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APPLICATION OF OPERATOR VIDEO BANDWIDTH COMPRESSION/REDUCTION RESEARCH TO RPV SYSTEM DESIGN

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An analytical program to compile, analyze, synthesize, and apply the results of past operator video bandwidth compression/reduction research to the design and development of the U.S. Army Remotely Piloted Vehicle Target Acquisition/Designation Aerial Reconnaissance System was conducted. The analytical work reported addressed the following five program tasks:

1) Compile available video bandwidth compression/reduction operator performance data;

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2) Develop mission/task descriptions for the Army RPV system Mission Payload Operator ;
3) Analyze and synthesize video bandwidth compression/reduction operator performance research data in terms of RPV system design parameters and operator tasks;
4) Derive recommended RPV bandwidth compression/reduction system design parameters; and
5) Identify critical Army RPV system research and simulation requirements.

PREFACE

Contractual support for this research was provided by the U.S. Army Electronics Research and Development Command, DELCS-I, Fort Monmouth, New Jersey, and the U.S. Army Aviation Research and Development Command, DRCPM-RPV-T, St. Louis, Missouri, contract number DAAB07-78-C-2415, Amendment 00003. Mr. A.J. Farnochi was the Army Program Manager, and Mr. M.L. Hershberger was the Hughes Aircraft Company Program Manager. The authors gratefully acknowledge the cooperation and technical information provided by RPV program personnel at Lockheed Missiles and Space Company, Sunnyvale, California.

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SECTION 1

INTRODUCTION AND SUMMARY

BACKGROUND

The U.S. Army's Remotely Piloted Vehicle (RPV) system, currently under development with Lockheed Missiles and Space Company of Sunnyvale, California, as the prime contractor, will provide reconnaissance, surveillance, target acquisition, adjustment of field artillery fire, target designation, and damage assessment support to combat elements of U.S. Army divisions. A central element of this system is a video data link that provides a remote operator the video imagery necessary to detect and recognize tactical vehicular-type targets and to direct sensor pointing for target designation and adjustment of artillery fire.

A major concern in the field use of video data link systems is electronic jamming. Video data links are wide bandwidth systems, and jamming effectiveness is directly proportional to bandwidth. The Army's RPV will use a digital data link; bandwidth for digital systems is typically expressed as data rate in transmitted bits per second. A conventional television system with 6 bits per picture element has a data rate of 4.5 megabits per second.

To be effective in hostile environments where jamming can be expected, countermeasures are necessary to abrogate enemy jamming. The primary countermeasure against enemy jamming of video data links is bandwidth compression/reduction. There are several techniques whereby the video data rate can be reduced using data compression transform techniques (the cosine/DPCM transform will be used with the Army RPV system) or simple bandwidth reduction, such as frame rate reduction and resolution reduction. Bandwidth compression can be combined with simple bandwidth reduction techniques to achieve a considerably reduced data rate, because the factors are multiplicative. For example, a 3:1 reduction via bandwidth compression, an 8:1 reduction via frame rate reduction, and a 4:1 reduction via resolution reduction would result in a 96:1 system bandwidth compression/reduction. For such a case, our conventional 4.5 megabits per second television system data rate would shrink to a 0.47 megabit per second data rate. Unfortunately, few things are truly free, and

bandwidth reduction/compression can degrade the quality of the sensor video information and interfere with the operator's ability to command sensor pointing.

Increased interest in RPV applications beyond simple non-real-time reconnaissance vehicles and the development of electro-optical guided weapons systems, like the GBU-15, has during the past 5 years fostered the funding of research to determine the effects of bandwidth compression/reduction on operator performance. It was the objective of this study to compile, analyze, synthesize, and apply the results of this past video bandwidth reduction/ compression research to the design and development of the U.S. Army Remotely Piloted Vehicle Target Acquisition/Designation Aerial Reconnaissance System.

SCOPE AND PURPOSE

The analytical work reported herein addressed the following five program tasks:

- Compile available data related to video bandwidth compression/ reduction and operator performance,
- Develop mission/task descriptions for the Mission Payload Operator of the Army RPV system,
- Analyze and synthesize video bandwidth compression/reduction operator performance data in terms of RPV system design parameters and RPV operator tasks,
- Derive recommended RPV bandwidth compression/reduction system design parameters,
- Identify critical research and simulation requirements.

The principal outputs of this effort were: 1) a review of the video bandwidth compression/reduction research literature, 2) RPV mission payload operator task procedure descriptions, 3) recommended video bandwidth compression/reduction design parameters that satisfy operator performance requirements, and 4) research and simulation requirements necessary for the resolution of issues that could not be satisfactorily answered based on existing information. The methodology used to achieve these ends included analysis and synthesis of data obtained from research reports, design documents, and personal communications. In this latter category, personnel from the U.S. Army ERADCOM, U.S. Army RPV Program Office, and Lockheed Missiles and Space Company were the primary sources.

SECTION 2

ANALYSIS AND SYNTHESIS OF VIDEO BANDWIDTH COMPRESSION/REDUCTION OPERATOR PERFORMANCE DATA

INTRODUCTION

A bibliographic literature search was conducted to identify potential sources of information related to RPV video bandwidth compression/reduction effects on operator target acquisition performance. As a result of this initial bibliographic search through the National Technical Information Service, as well as the Hughes Aircraft Company technical library and libraries of personnel at Hughes Aircraft Company, 73 documents were obtained. These documents were culled for information on video bandwidth compression/reduction and operator performance in the following areas of interest: video data compression, video frame rate reduction, sensor resolution, sensor field of view, and sensor video truncation. This process resulted in the identification of 19 technical reports that warranted detailed review. A summary of the information contained in the 19 reports is provided below for each of the five areas of interest.

TECHNICAL REPORTS SUMMARY

Video Data Compression

The most recent research on video bandwidth compression and operator performance was conducted for the U.S. Army Electronics Research & Development Command in support of the Army RPV development program.[1] A RCA developed cosine/DPCM video image transform system interfaced to a Hughes RPV simulation facility was used to conduct the bandwidth compression research. Bandwidth

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[1] Agin, A. K., Hershberger, M. L., and Lukosevicius, A. V., Video Bandwidth Reduction/Compression Research for the Army Remotely Piloted Vehicle System. Hughes Aircraft Company, Hughes Report No. P00682, Contract No. DAAB07-78-C-2415, October 1980.

compression levels of 0.4, 0.8, 1.6, 3.2, and 6.0 bits per picture element were investigated in combination with:

- 5-, 10-, and 40-kilometer atmospheric visibilities,
- Armored personnel carrier, tank, 170-mm self-propelled gun, 2-1/2 ton truck, and jeep target types,
- single and groups of 10 targets (target numerosity),
- broadside and 45-degree forward quartering target aspects, and
- low, medium, and high rated levels of target scene background complexity.

The primary measure of operator task performance was the number of TV lines across the targets' height when detection and recognition occurred.

Both bandwidth compression and target numerosity had large and highly statistically reliable effects on operator target detection and recognition performance. These two parameters were also found to interact with each other. Figures 1 and 2 show this interaction effect for target detection and target recognition performance, respectively. Figure 1 shows that bandwidth compression had no affect on the operators' ability to detect groups of 10 targets. Single targets, on the other hand, were much more difficult to detect, and the image quality degradation caused by the higher bandwidth compression levels made the operators' task more difficult. The interaction between bandwidth compression and target numerosity for target recognition, shown in Figure 2, also indicates that groups of 10 targets are less susceptible to bandwidth compression performance degradation than single targets.

These results indicate that single targets place the driving requirement on the level of bandwidth compression that can be achieved without major degradation of operator target detection and recognition performance. This level of compression is in the region of 2 bits per picture element.

An earlier study also directed at Army RPV systems development and sponsored by the Naval Ocean Systems Center in San Diego, California, investigated the effects of cosine/DPCM bandwidth compression on operator tactical target recognition performance.[2] The study investigated the nine combinations of 5-,

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[2] Hershberger, M. L., Operator performance evaluation of mini-RPV video image bandwidth reduction/compression techniques, in Image Transmission Via Spread Spectrum Techniques, ARPA Annual Technical Report January 1977 - December 1977, ARPA QR8, January 1978.

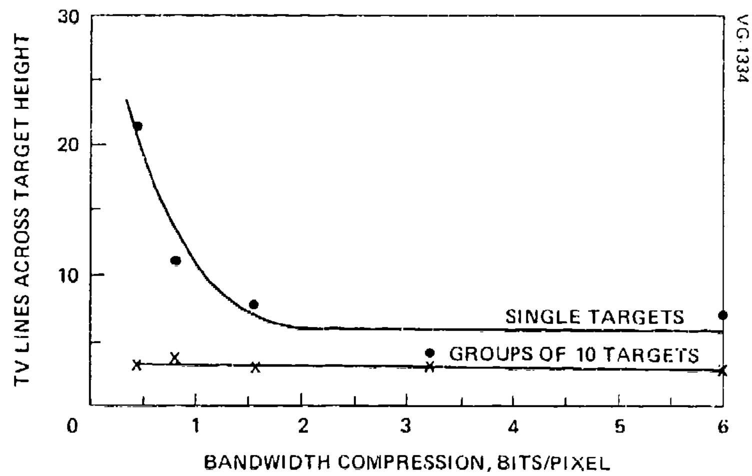

Figure 1. Interaction between bandwidth compression and target numerosity for target detection performance.

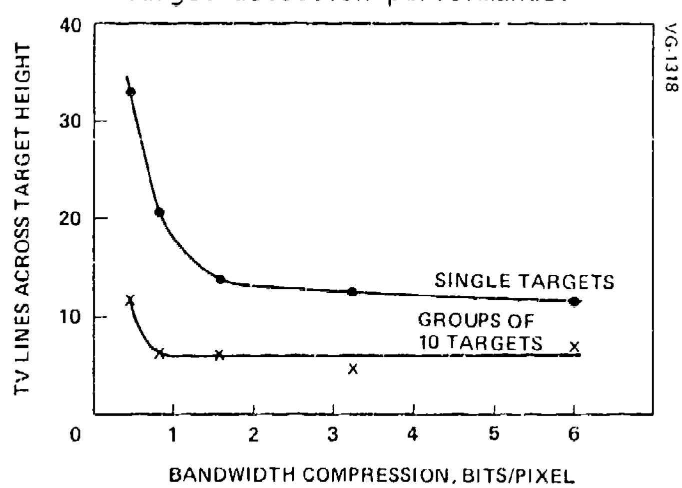

Figure 2. Interaction between bandwidth compression and target numerosity for target recognition performance.

2-, and 1-bit per picture element (pixel) compression and zero, 10^{-3}, and 10^{-2} bit error rate jamming. In addition, a special uncompressed (6 bits per pixel) video condition was investigated as a baseline comparison. The Naval Ocean Systems Center's hybrid cosine/DPCM transform system was interfaced with the Hughes RPV simulator to provide the facility for conducting the study. The transform system was limited to 100 by 100 picture element resolution. As a result, very narrow sensor fields of view had to be used, and the operators'

task was therefore limited to the recognition of tactical vehicle-size targets. The number of sensor resolution elements across the height of the tactical targets was the performance measure used to assess the effects of bandwidth compression and bit error rate jamming on operator target recognition performance.

The results of the study, depicted in Figure 3, showed there was no degradation of operator performance, compared to the baseline uncompressed video condition, until 6:1 compression (1 bit per pixel) was reached. Bit error rate jamming had no effect on operator tactical target recognition performance, as shown in Figure 4. The number of resolution elements required for target recognition at the uncompressed video condition and the 5 and 2 bits per pixel compressed video conditions agreed well with other research findings.[3] It was concluded that RPVs could operate at 10^{-2} bit error rate jamming levels with 1.5 bits per picture element with minimal degradation of operator performance.

The Air Force has also sponsored video bandwidth compression/reduction operator performance research in support of air-to-ground strike RPV applications. Although this research in less applicable to Army RPV systems, because the targets used in the Air Force sponsored research were, for the most part, large fixed targets, the results may be useful for other Army missions. One such study[4] was conducted by Hughes Aircraft Company using a one-dimensional Hadamard transform system interfaced to a RPV simulator. Bandwidth compressions of 0.5, 0.6, 1.0, 2.0, and 6.0 bits per pixel and bit error rates of 0, 10^{-3}, and 10^{-2} were investigated. The operators' tasks were to locate and designate prebriefed targets (bridges, refineries, dams, POL storage areas, buildings, and factories) as the RPV closed on the target area. The range from the RPV to the target at target designation was measured.

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[3] Johnson, J., Analysis of image forming systems, in Image Intensifier Symposium, Fort Belvoir, Virginia, October 6 and 7, 1958 (AD220160).

[4] Hershberger, M. L. and Vanderkolk, R. J., Video Image Bandwidth Reduction/ Compression for Remotely Piloted Vehicles. Hughes Aircraft Company, Hughes Report No. P76-243R, Contract No. F33657-75-C-0532, October 1976.

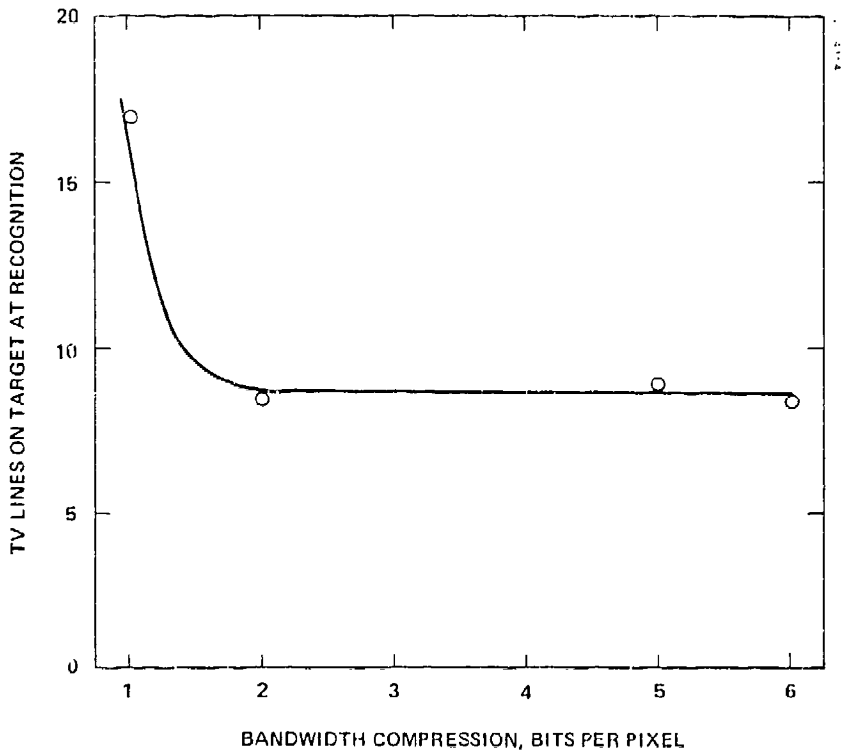

Figure 3. Effects of bandwidth compression on operator tactical target recognition performance.

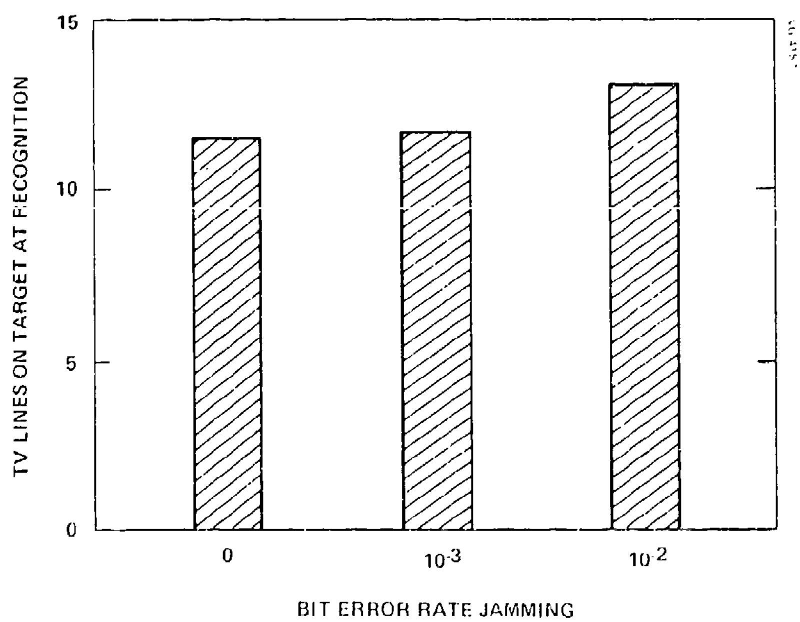

Figure 4. Effects of bit error rate noise jamming on operator tactical target recognition performance.

Bit error rate jamming had a negligible affect on operator performance as shown in Figure 5. The effects of bandwidth compression on operator performance, as shown in Figure 6, were negligible from 1.0 to 6.0 bits per pixel. Moderate performance degradation occurred at the 0.6- and 0.5-bit per pixel compressions.

A simulation of 10 bandwidth compression/reduction systems composed of one-dimension Hadamard transform compression and sensor resolution reduction with and without jamming was also conducted during the Air Force sponsored study. The results, shown in Figure 7, confirmed the earlier bandwidth compression results.

The results of the simulation also indicated that operator performance is not a simple function of the amount of bandwidth reduction/compression. It is how much reduction or compression is obtained for a given reduction/compression technique. For example, a 256- by 256-element resolution and 1-bit per pixel compression system which provided a 24:1 bandwidth reduction/compression was far superior to a 512- by 512-element resolution and 0.5-bit per pixel compression system which provided only half as much (12:1) bandwidth reduction/compression. It appears that bandwidth reduction/compression can be achieved with resolution reduction and bandwidth compression without loss of operator performance but only within certain limits.

The Army has also been interested in the application of video bandwidth compression for intelligence extraction by photo image interpreters. In a recent study[5], the effects of 0.8-, 1.0-, 2.0-, and 8.0-bit per pixel compression on the interpretation of 100- by 100-foot photo-chips containing tactical vehicle-type targets were investigated. Bandwidth compression was achieved using a 2-dimensional cosine transform. Figure 8 shows some of the results obtained in the study. The general conclusion based on the results obtained was that bandwidth compression reduces the number of targets detected

[5] Martinek, H. and Zarin, A., The Effects of Bandwidth Compression on Image Interpreter Performance. U.S. Army Research Institute, ARI-TR-396, August 1979.

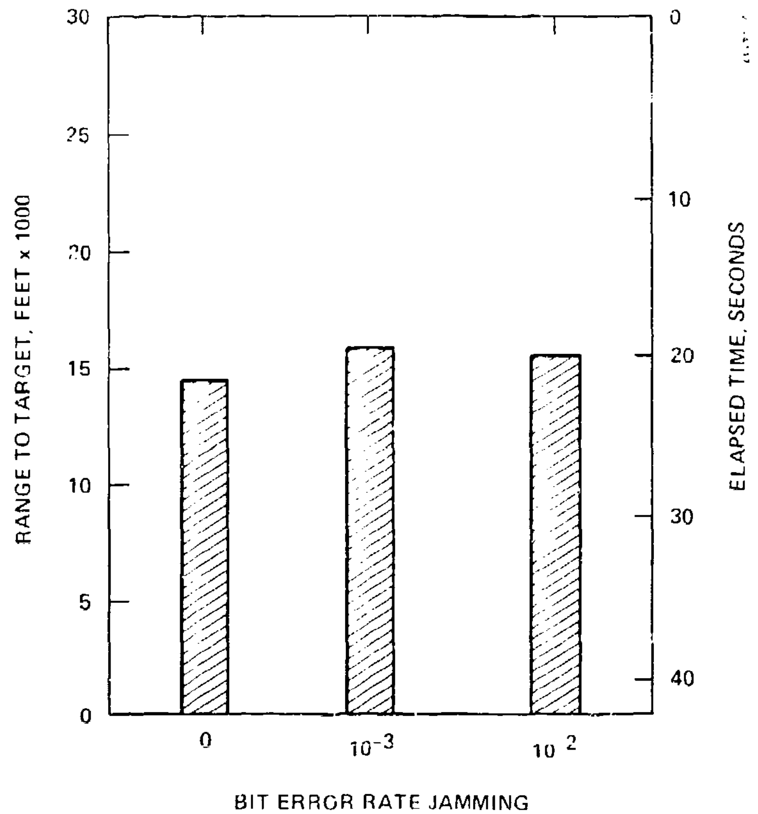

Figure 5. Effects of bit error rate jamming on operator target acquisition performance.

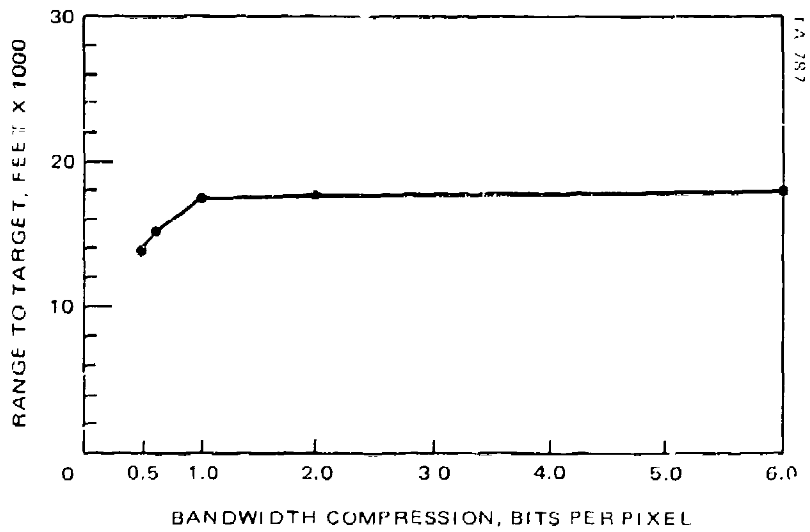

Figure 6. Effect of bandwidth compression on operator target acquisition performance.

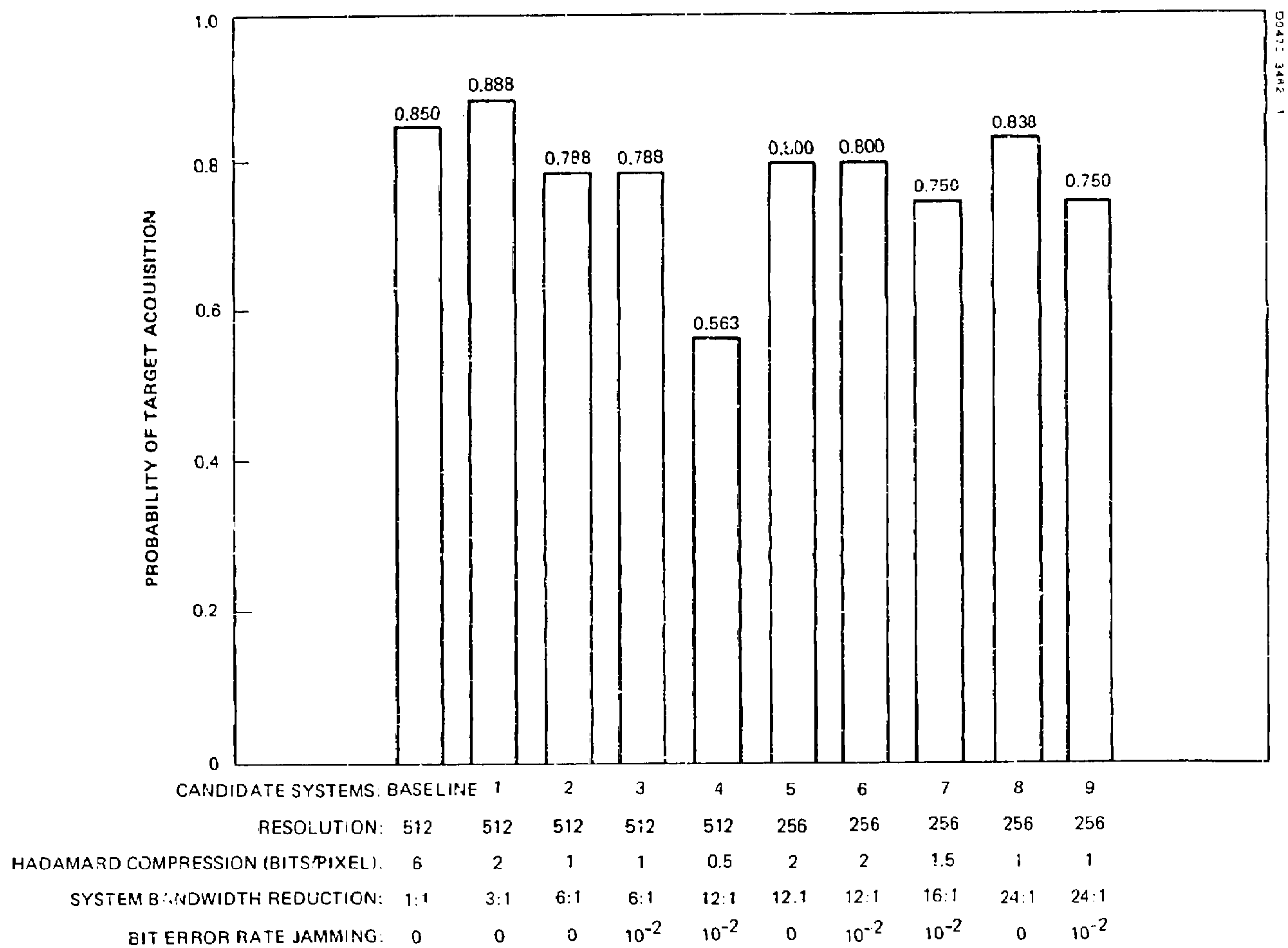

Figure 7. Results of bandwidth reduction/compression systems simulation.

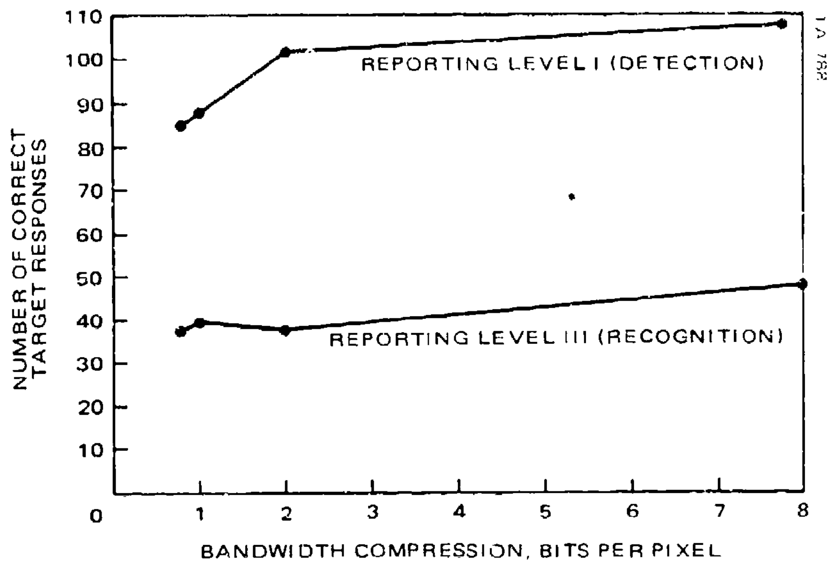

Figure 8. Effects of bandwidth compression on image interpreter performance. (Adapted from Martinek and Zarin, 1979.)

and identified by image interpreters, and while there is some reduction in performance at 2-bit per pixel compression, the largest decrease is between the 2-bit per pixel and 1-bit per pixel compressions.

The U.S. Army Night Vision & Electro-Optics Laboratory at Fort Belvoir, Virginia, has also been supporting the development of the Army RPV system. As part of this support, the effect of bandwidth compression on military target detection performance was recently investigated.[6]

Television imagery recorded during a preliminary field evaluation of the Army's RPV system at Fort Huachuca, Arizona, was processed using a HAAR transform to produce compressions at 0.5, 2.0, and 8.0 bits per pixel. Operators attempted to locate (detect) single tactical vehicle-type targets (jeeps, 5/4-ton trucks, 2-1/2-ton trucks, and APCs) in desert scenes with scrub pine trees. Target detection time was measured and transformed to range-to-target at detection. The results, shown in Figure 9, indicate an almost linear

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[6]Swistak, J. E., Effect of Spatial and Temporal Video Image Compression on Military Target Detection, U.S. Army Night Vision & Electro-Optics Laboratory, Fort Belvoir, Virginia, Report No. DELNV-TR-0010, April 1980.

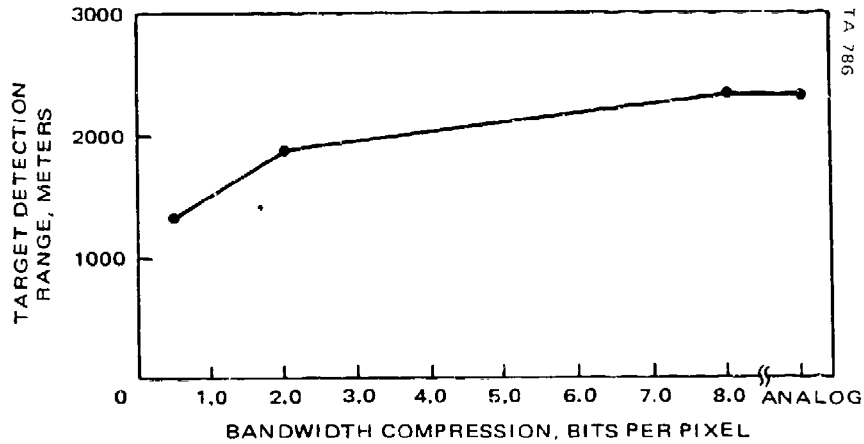

Figure 9. Effects of bandwidth compression on tactical target detection performance (adapted from Swistak, 1980).

improvement in target detection performance as the number of bits per pixel increase from 0.5 to 8.0. Between 8 bits per pixel and analog video, performance was essentially constant.

A partial replication of the above study was conducted using cosine/DPCM transformed television imagery at 2- and 8-bit per pixel compression and uncompressed analog video for Lockheed Missiles and Space Company.[7] The cosine/DPCM transformed imagery was computer generated at Lockheed for use in the study conducted at the Army Night Vision & Electro-Optics Laboratory facilities. The results showed slightly better performance at 2-bit per pixel compression (2166-meter target detection) compared to the 8-bit per pixel and analog conditions (2053-meter detection). However, the slight advantage for the 2-bit per pixel compression was not statistically reliable.

The six studies of operator performance and bandwidth compression are summarized in Table 1. The three studies that used cosine/DPCM transform bandwidth compression all indicated either minor or no degradation of operator tactical target detection or tactical target recognition performance at 1.5 to 2.0 bit per pixel compression.

[7]Personnel Communication from H.B. Iverson, Lockheed Missiles and Space Company, February 1981.

TABLE 1. SUMMARY OF BANDWIDTH COMPRESSION STUDIES

Study	Type Compression	Task/Target	Results
Agin, Hershberger, and Lukosevicius, 1980	Cosine/DPCM	Detection and recognition of single and groups of 10 targets	1.6 bits/pixel acceptable for single targets; 0.4 bit/pixel acceptable for detection of groups of targets; 1.6 bits/pixel acceptable for target recognition.
Hershberger, 1978	Cosine/DPCM	Target recognition	1.5 to 2.0 bits/pixel acceptable.
Hershberger and Vanderkolk, 1976	One-dimensional Hadamard	Acquisition of large fixed targets	1.0 bit/pixel acceptable
Martinek and Zarin, 1979	2-dimensional cosine	Tactical target image interpretation	Some performance degradation at 2 bits/pixel; large degradation at 1.0 bit/pixel.
Swistak, 1980	HAAR	Tactical target detection	20 percent performance degradation between 8.0 and 2.0 bits/pixel; 29 percent performance degradation between 2.0 and 0.5 bits/pixel.
Iverson, 1980 (Personal Communication)	Cosine/DPCM	Tactical target detection	No appreciable performance differences among 2 and 8 bits/pixel and analog video.

Two of the three studies that investigated bandwidth compression at or below 1.0 bit per pixel found relatively large performance degradation at those compression levels. The two studies that investigated tactical targets with either the 2-dimensional cosine transform or the Haar transform obtained between 6 and 21 percent performance degradation at 2 bits per pixel.

Taken together, the findings of the available research on video bandwidth compression and operator tactical target detection and recognition performance indicate that with the cosine/DPCM transform, compressions between 1.5 and 2.0 bits per pixel will result in performance that is essentially equivalent to video images with 6.0 bits per pixel or greater. Since the Army RPV system will utilize the cosine/DPCM transform as part of its modular integrated communication/navigation system (MICNS), a compression of 1.5 to 2.0 bits per pixel is indicated. This represents a compression ratio of 4:1 to 3:1 compared to a standard 6.0-bit per pixel quantization. At worst, a 20 percent performance degradation, as found in the studies that used the 2-dimensional cosine and the Haar transform, might occur with 2-bit per pixel compression.

The fact that the three studies which used the cosine/DPCM compression employed different hardware implementations or computer generated transform imagery, different target imagery, and different study procedures indicates a consistent trend for 1.5- to 2.0-bit per pixel compression to provide essentially degradation-free operator target detection and recognition performance.

Video Frame Rate Reduction

The single largest potential reduction of video bandwidth is via frame rate reduction. Compared to a 30-frame per second frame rate, a 1-frame per second frame rate would result in a 30:1 bandwidth reduction; a 0.12-frame per second frame rate would result in a 250:1 bandwidth reduction. Frame rate reduction for RPVs has been fairly recently investigated for its effects on target detection and recognition, coarse sensor slewing, precision sensor slewing, and target tracking.

Target Detection and Recognition. One of the earliest studies of video frame rate on operator performance was performed by the Air Force Aeromedical

Research Laboratory[8] in which the effects of 1-, 3-, 8-, and 23-frame per second frame rates on operator target recognition performance were investigated. The results, shown in Figure 10, indicate a slight trend for operator performance (range-to-target at recognition) to improve as frame rate increased from 1 to 8 frames per second. The differences among the four frame rates were not, however, statistically reliable. It was therefore concluded that frame rates as low as 1 frame per second do not degrade RPV operator target recognition performance.

In the research by Hershberger and Vanderkolk,[4] 0.23-, 0.94-, 3.75-, and 7.5-frame per second frame rates were investigated for both target recognition and precision sensor slewing. The results of this study for target recognition performance are shown in Figures 11 and 12. Figure 11 indicates a performance degradation at the 0.23-frame per second frame rate and equivalent performance at 0.94-, 3.75-, and 7.5-frame per second frame rates. In this study, there was an initial 1 to 2 frame transmission delay before the operators saw the first video frame; this resulted in an initial range or time penalty. For the 0.23-frame per second rate, this penalty was 5,040 feet (the simulated RPV speed was 680 feet per second); the penalty was 45 feet with the 7.5-frame per second rate. When the operator target recognition performance data are corrected for differences in transmission delay with

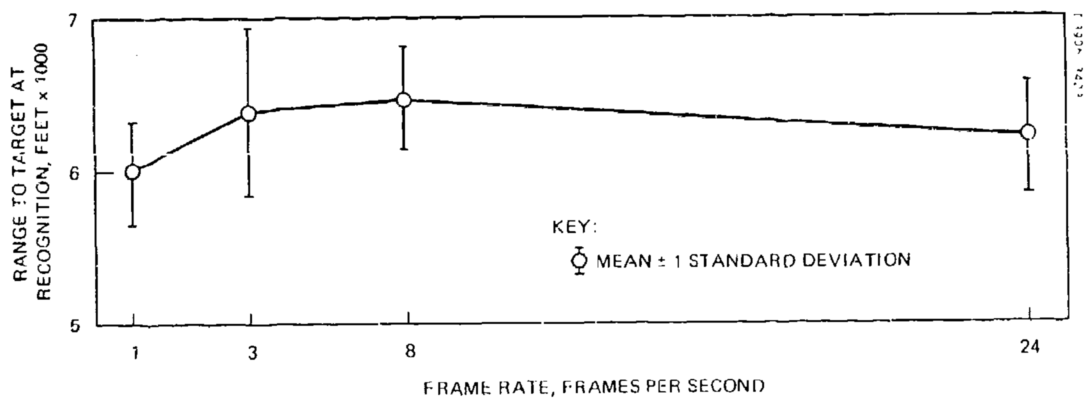

Figure 10. Effect of video frame rate on operator target recognition performance.

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[8] Self, H.C. and Heckart, S.A., TV Target Acquisition at Various Frame Rates, Technical Report AMRL-TR-73-111. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, September 1973.

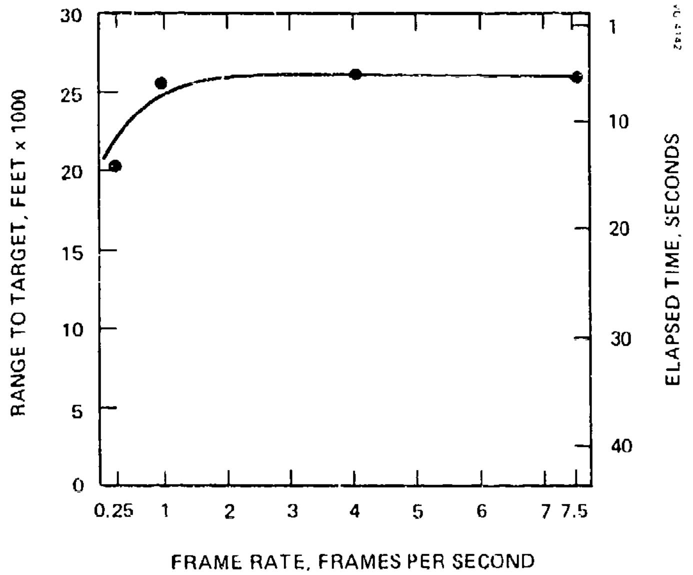

Figure 11. Frame rate effects on operator target recognition performance.

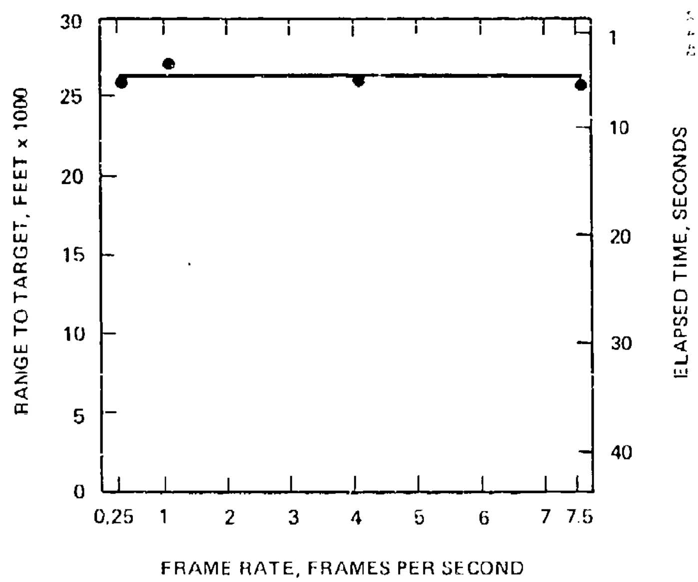

Figure 12. Frame rate effects on operator target recognition performance with transmission delay taken out.

the four frame rates, the results shown in Figure 12 are obtained. Operator target recognition performance as a function of frame rate with transmission delay eliminated was a flat, straight line function.

The effect of video frame rate on operator detection of tactical targets was also investigated by the Army Night Vision & Electro-Optics Laboratory in combination with video bandwidth compression.[6] The frame rates investigated were 1, 3, 6, 10, and 30 frames per second. As shown in Figure 13, there were no appreciable differences in mean target detection range as a function of frame rate. Frame rate also did not interact with video bandwidth compression. That is, the effects of frame rate and bandwidth compression on operator target detection performance were independent.

The three studies which investigated the effects of video frame rate on RPV operator target detection and recognition performance clearly indicate that reducing frame rate to as low as 0.23 frame per second does not degrade the operators' performance. Frame rates less than 1 frame per second, however, result in an initial frame delay that is measurably reflected in operator target detection/recognition range or time performance, but which the operator has no control over.

Very low frame rates can affect target detection/recognition performance if the RPV flys a distance (determined by the sensor field of view, sensor

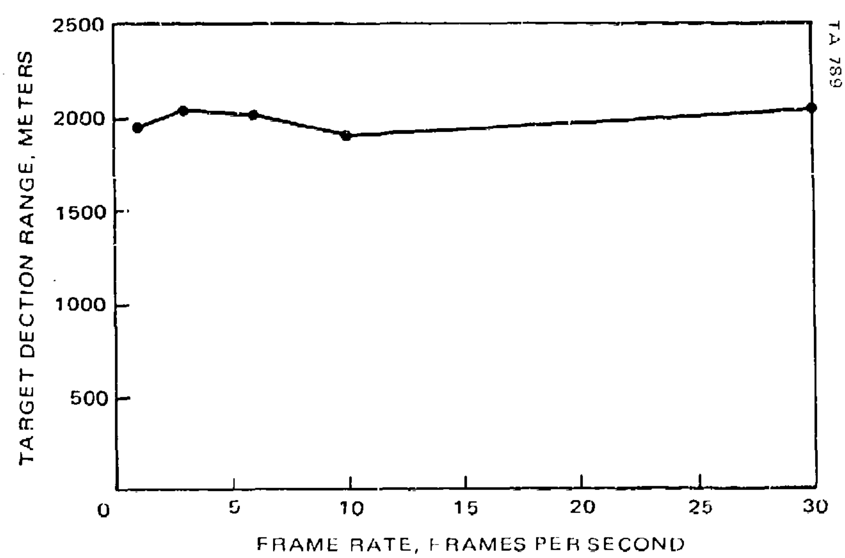

Figure 13. Effect of frame rate on operator tactical target detection (adapted from Swistak, 1980).

depression angle, RPV speed, and RPV altitude) in less time then the interframe interval. The current Army RPV system design, under certain conditions, utilizes a 0.12 frame per second frame rate during search to achieve a reduced data rate, resulting in an interframe interval of 8.5 seconds. With a 20-degree sensor field of view, a 25-degree sensor depression angle, a 130-kilometer per hour RPV speed, and a 1000-meter RPV altitude, it would take the RPV 38 seconds to fly the distance covered by a 20-degree sensor field of view depressed 25 degrees. Since the time to traverse the distance is greater than the 8.5-second interframe interval, there will be no loss of displayed ground coverage. Under the same conditions, but with a 4.8-degree field of view, the time for the RPV to fly the distance is 7.8 seconds, which is just slightly less than the 8.5-second interframe interval. Thus with the lowest 0.12-frame per second frame rate being considered for the RPV and with the nominal planned RPV mission sensor depression angle, altitude, and speed parameters, there will be no major loss of displayed ground area with sensor fields of view as small as 4.8 degrees. Since this potential problem would only occur during search when the autotracker is not engaged and when small fields of view are unlikely to be used, it is not anticipated that very low frame rates will result in a failure to detect/recognize targets because the targets were not mapped by the sensor.

Coarse Sensor Slewing. For the Army's RPV mission, coarse sensor slewing could be used to search a ground area larger than the instantaneous sensor field of view. The search function could be accomplished: 1) by preprogrammed flight of the RPV within the desired flight corridors, 2) by using automatic preprogrammed sensor slewing within the sensor's field of regard, 3) by allowing the RPV Mission Payload Operator to manually slew the sensor within its field of regard, or 4) by the use of some combination of the above three techniques.

Operator manual sensor slewing would appear to be a desirable design approach because of the adaptive and intelligent behavior that the human operator can bring to bear during the search process. However, the need to operate with reduced video bandwidth in jamming environments via frame rate reduction may result in a system which is extremely difficult for operators to use.

One research study has been conducted to investigate the effects of video frame rate on operator coarse sensor slewing performance.[1] This study, specifically directed at the Army RPV system, investigated 0.12-, 0.47-, 1.88-, and 7.5-frame per second frame rates in combination 5-, 10-, and 15-degree diagonal sensor fields of view and three control modes.

The three control modes investigated were: continuous rate control, image motion compensation, and bang-bang. Table 2 gives the major parameters of the three control modes. The continuous rate control mode was designed to allow operators to make smooth sensor slewing commands through a high sampling rate (30 Hz) and multidirectional responses from a x-y force transducer hand control. The force transducer responded to thumb pressure in any direction with reference to the x and y axes of the display. The output of the transducer was proportional to the force of the input; processing by digital computer introduced a shaping function such that the output was proportional to the square of the input. The maximum slewing rate that could be achieved was 20 degrees per second. There was a constant 80 mph RPV fly-over rate introduced through software processing. A single crosshair reference symbol was fixed at the center of the display.

TABLE 2. MAJOR DESIGN PARAMETERS OF THE THREE CONTROL MODES

Design Parameter	Control Mode		
	Continuous	Image Motion Compensation	Bang-Bang
Hand Control	Force Transducer	Force Transducer	Two-Axis Thumb Switch
Shaping Function	$\Sigma(aX/X/)$ if $X > k$	$\Sigma(aX/X/)$ if $X > k$	Fixed Increment (10 Hz) Linear Function of Time (X), if $X > k$
Maximum Slew Rate	20^{o}/Sec	20^{o}/Sec	8^{o}/Sec
Fly-Over	80 mph	Ground Stabilized	80 mph
Symbols	+	+ ⁄ ||	+
Polarity	$\pm X$, $\pm Y$; Selectable	$\pm X$, $\pm Y$; Selectable	$\pm X$, $\pm Y$; Selectable
Limits	C($\pm$10 Volts) where C = Scaling for FOV	C($\pm$10 Volts)	C($\pm$10 Volts)

The image motion compensation (IMC) mode used the same force transducer control as in the continuous control mode. The shaping function was the same, and the maximum slewing rate was also 20 degrees per second. The IMC mode was different from the continuous control mode in two major respects: (1) information about the system response to the hand control input was provided and (2) there was complete ground-stabilized image motion compensation which eliminated the vertical fly-over displacement of the terrain.

The system response information was provided by three symbols. The center reference crosshair was stationary as in the continuous control mode. A diamond (◊) symbol indicated the position of the sensor in real-time as a function of the current hand control input and transmission delay. A two bar (||) symbol indicated the position the sensor would take on the next frame update. At low frame rates, operators would see the diamond move as they input a displacement signal through the hand control. The two bar symbol would follow, and then stop at the position of the next displayed frame. At the next displayed frame, the point on the image where the two bars had been would be under the center reference crosshair. If no further input had been made, the next displayed frame after that would have the crosshair, two bars, and diamond coincident on the display. At high frame rates, the three symbols would appear to follow each other, with the diamond (new position) leading and the two bars (next frame) following. The result of the three symbol feedback was that the operator knew where he was slewing and what point on the image would be at the center of the display at the next update.

The bang-bang control mode was implemented with a two-axis thumb switch. The switch could be pushed to the left, right, up, or down with respect to the display. The bang-bang mode was an incremental input mode. The response was linear with respect to the number of input pulses generated at the hand control. The hand control input was sampled at 10 Hz, and each sample was equal to a sensor slewing displacement of 0.80 degree. The maximum slewing rate was therefore 8 degrees per second. Each pulse did not have to originate with a thumb switch displacement, holding the switch in the "on" position would result in an incremental rate. There was a simulated RPV fly-over rate of 80 mph as in the continuous control mode. The operator could slew the sensor by discrete switch pulses in any combination of up, down, left, or right inputs to achieve the desired displacement.

The operators' task in the study was to slew the simulated TV sensor and search the displayed field of view until the target was in the field of view and detected. Time and probability of successful task accomplishment were measured.

Figures 14 and 15 show the main effect of frame rate on coarse sensor slewing. It is clear from the two figures that coarse sensor slewing performance (target search) improved rapidly as frame rate increased from 0.12 to 1.88 frames per second, and only a slight improvement occurred between 1.88 and 7.5 frames per second. Frame rate did not interact with sensor control mode.

For an operator to perform manual sensor slewing for large area target search, the video frame rate should be on the order of 2 frames per second or greater. As shown in Figures 16 and 17, the choice of particular control mode will have little affect on the operator's large area sensor slewing performance as long as the particular control mode is reasonably well designed.

Precision Sensor Slewing. Once a target has been detected, the RPV Mission Payload Operator will be required to position the sensor such that the target will be near the center of the search field of view so that a reduced field of view can be selected for target recognition. This process will require precision sensor slewing.

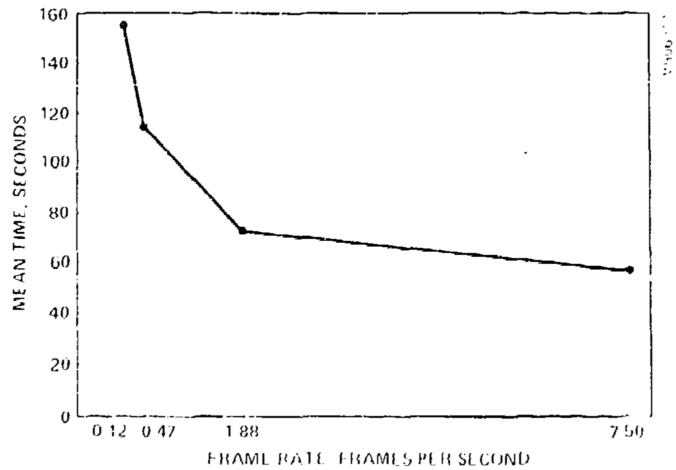

Figure 14. Effects of video frame rate on target search time.

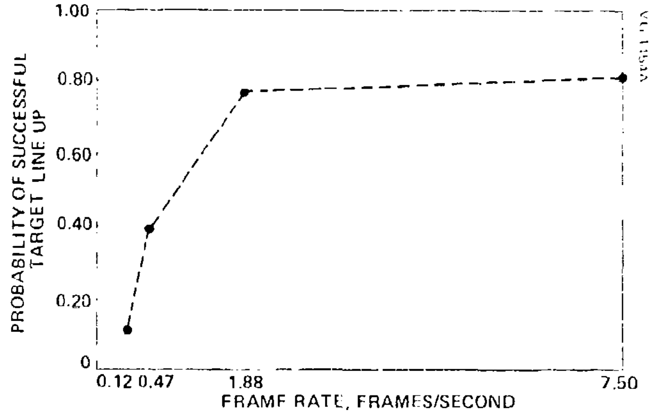

Figure 15. Effect of video frame rate on probability of successful target search.

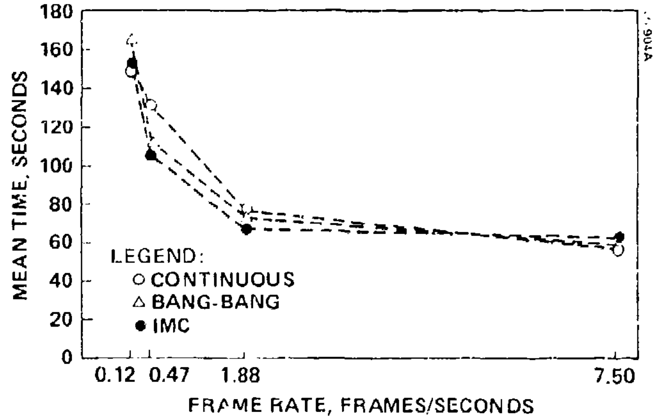

Figure 16. Interaction between video frame rate and sensor control mode for operator task time.

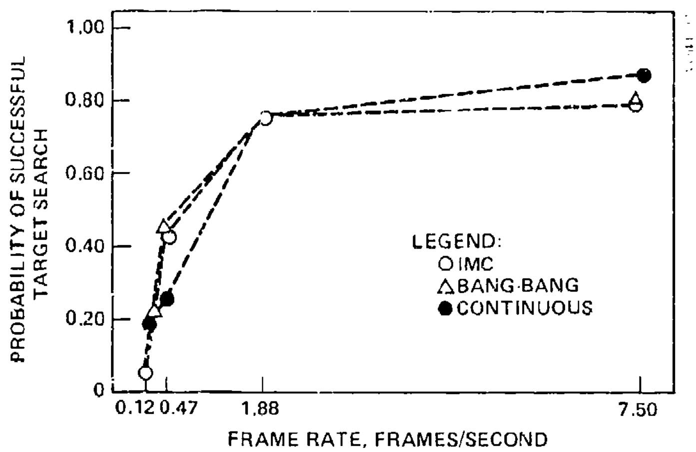

Figure 17. Interaction between video frame rate and sensor control mode for probability of successful target search.

Three studies of the effects of video frame rate on precision sensor slewing performance for RPV applications have been conducted. In a study conducted for the Naval Ocean Systems Center,[2] frame rates of 0.94, 1.88, 3.75, 7.5, 15.0 and 30.0 frames per second were investigated. A 2-axis position displacement hand control was used by the operators to input sensor rate commands to a simulated 3-axis stabilized sensor. At the start of a trial, a tank target was positioned at a random position on the display and was drifting at 50 meters per second. The drift rate was due to a simulated vehicle/target geometry in which the RPV was flying at a 762-meter altitude, a speed of 50 meters per second, and an initial ground range-to-target of 3000 meters. The sensor field of view was 2 degrees.

The effect of frame rate on precision sensor slewing time is shown in Figure 18. Slewing time ranged from 16 seconds at the 30-frame per second frame rate to 61 seconds at the 0.94-frame per second frame rate – nearly a four times increase in the time required to position the target near the fixed reticle in the center of the display. The largest reduction in time as frame rate increased was between 0.94 and 3.75 frames per second (33 seconds). Between 3.75 and 15 frames per second, the reduction was more gradual (13 seconds). There was no appreciable difference between 15- and 30-frame per second frame rates.

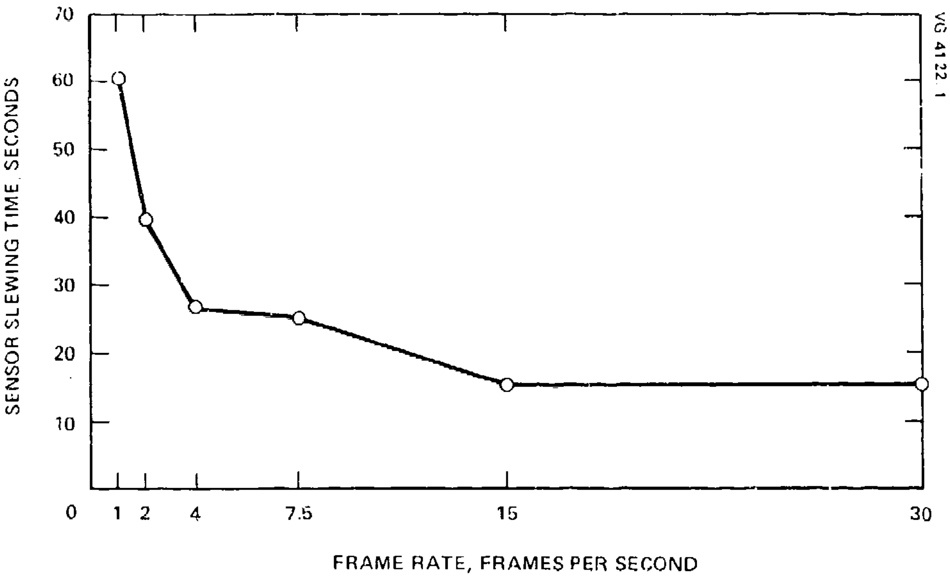

Figure 18. Effects of frame rate on slewing time.

The time data are indicative of the task difficulty with the various frame rates and thus provide an index of the relative time required to accomplish precision sensor slewing for frame rates from 0.94 to 30 frames per second. Clearly, 0.94 and 1.88 frame per second frame rates are extremely difficult to use, 3.75 and 7.5 frames per second frame rates are of moderate difficulty, and 15 and 30 frames per second frame rates can be used with relative ease.

Figure 19 shows the effect of frame rate on radial slewing error. Slewing error ranged from 4.46 milliradians at the 0.94-frame per second frame rate to 0.82 milliradian at the 30-frames per second frame rate — a greater than 5 to 1 difference. It is obvious from Figure 19 that the largest improvement occurred as frame rate increased from 0.94 to 1.88 frames per second (from 4.56 to 1.56 milliradians error). There was a more gradual improvement as frame rate increased from 1.88 to 7.5 frames per second (1.56 to 0.88 milliradians error). Slewing error was essentially constant from 7.5 to 30 frames per second (0.88 to 0.82 milliradian designation error). A Newman-Keuls simultaneous test for multiple contrasts was used to test for the reliability of differences among each of the pairs of frame rates. The results of this test showed that the 0.94 frame per second frame rate produced significantly

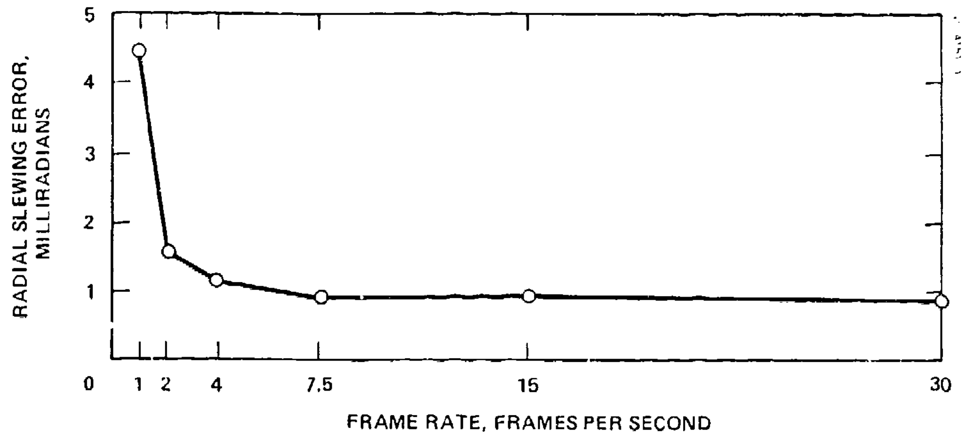

Figure 19. Effects of frame rate on precision sensor slewing accuracy.

($p < 0.01$) greater designation error than the other five frame rates. Differences among the 1.88, 3.75, 7.5, 15, and 30 frame per second frame rates, however, were not statistically reliable. One can therefore conclude that frame rates of 1.88 frames per second or greater will result in equivalent operator precision sensor slewing accuracy.

The second study of video frame rate reduction on precision sensor slewing, conducted for the Air Force for application to strike RPVs, investigated 0.23-, 0.94-, 3.75-, and 7.5-frame per second rates in combination with rate control, cursor designation, and image motion compensation control modes.[4]

In the rate control mode, displacement of the operator's hand control introduced azimuth and/or elevation rate commands to control the pointing angles of a 3-axis gimballed, ground stabilized sensor. The operators observed the results of their control commands by observation of the video scene.

In the motion compensation mode, video transmission delay was compensated by encoding the stabilized sensor gimbal angles at the beginning and end of the video frame transmission and correcting the video presentation on the TV monitor by the progressive difference in gimbal angles. The effect was to produce continuous control of video image slewing, analogous to a 30-frame per second update rate. Between video frame updates, portions of the display where the video had been slewed from were blanked. For example, if an operator slewed the image up 2 degrees and to the left 2 degrees the bottom

right-hand 2 degree portion of the display was blanked, because no video in this area existed in the scan converter memory.

The cursor designation control mode had two sub-modes: 1) 3-axis stabilized sensor pointing and 2) image freeze with cursor positioning. This mode worked in the following manner. At the start of a trial run, operators slewed the stabilized sensor to get the target anywhere within the sensor field of view. When an operator recognized the target or target area and had the target in the sensor field of view, he depressed a trigger switch on the hand control which simultaneously froze the displayed scene and enabled a moveable cursor on the display. With the trigger depressed, the cursor responded to position commands from the hand control. The operator then placed the cursor over the target. If he was sure of his designation accuracy at this point he was free to command lock-on by depressing a button also located on the hand control. If he decided, however, to reposition the target, the operator released the trigger. This caused the area under the cursor to move to the center of the display and returned the operator to the stabilized sensor mode. This process could be repeated until the operator was sure of his designation accuracy at which point he commanded sensor lock-on.

The vehicle/target mission geometry for this study was the computer model of a BGM-34 RPV with attitude hold autopilot flying at 680 feet per second with a 0.5 fuel load. The RPV popped up at a 30,000-foot range to the target and closed to a minimum range of 1500 feet to the target. A crosstrack navigation error of 1700 feet was simulated with a 20-degree TV sensor field of view. A 525-line TV sensor resolution with 6-bits gray level encoding was simulated. The 14-inch diagonal display was refreshed at 30 frames per second with 2:1 interlace.

Figure 20 shows the effect of frame rate and control mode on operator performance. Frame rate had no effect on operator precision sensor slewing with the cursor designation and the motion compensation control modes. The cursor designation mode was slightly superior to the motion compensation mode. Apparently the operators found it easier to use the cursor designation mode and thus could acquire targets slightly faster (a longer range-to-target). The average difference between the two modes was 3 seconds.

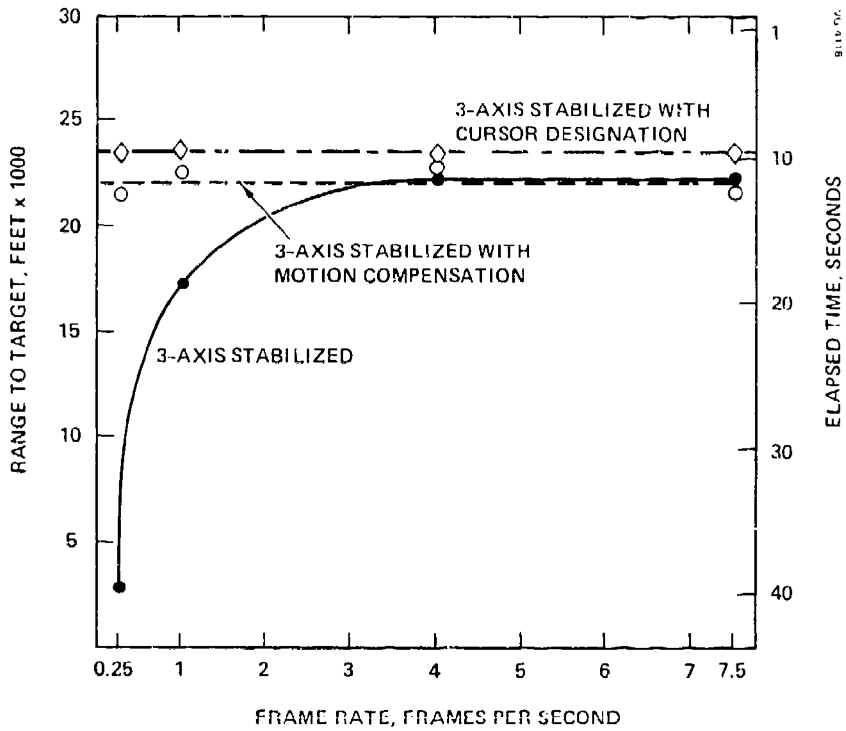

Figure 20. Effects of frame rate and control mode on operator precision sensor slewing performance.

With the 3-axis stabilized rate control mode, operator performance degraded rapidly as frame rate was reduced below 3.75 frames per second. Between 3.75- and 0.94-frame per second rates, range-to-target at acquisition went from 21,703 feet to 15,205 feet. Performance was constant between 3.75 and 7.5 frames per second with the 3-axis stabilized rate control mode.

The study results indicate that operators can acquire targets (control sensor pointing) with frame rates as low as 0.23 frame per second using either the cursor designation or the motion compensation control modes without any degradation of their performance. If an unaided 3-axis stabilized rate control system is used, performance degradation can be expected with video frame rates below 3.75 frames per second.

Precision sensor slewing was also investigated as part of the previously cited study in which the effects of frame rate and control mode on coarse sensor slewing were investigated.[1] A second operator task in that study

required the operators to slew the sensor so that the target was near the center of the displayed sensor field of view. As before, the four frame rates investigated were 0.12, 0.47, 1.88, and 7.5 frames per second, and the three control modes were continuous rate control, image motion compensation, and bang-bang.

The effects of video frame rate on the mean time to accomplish the precision sensor slewing task are shown in Figure 21; time increased in an approximately exponential function as frame rate decreased. The differences between the 7.5- and 1.88-frames per second frame rates were small compared to the differences between the 0.47- and 0.12-frame per second frame rates. Although, the time difference between 7.5- and 1.88-frames per second frame rates was not statistically reliable, the difference may be operationally meaningful. As has been demonstrated in previous studies of video frame rate, sensor control becomes more difficult as frame rate decreases, and the increased task difficulty is more pronounced with frame rates below 1 to 2 frames per second.

Figure 22 shows the effects of video frame rate on the probability of successful precision sensor slewing. The relationship between frame rate and probability of successful sensor slewing is exponential, as was the case for task time. The time and probability data are largely comparable with respect to video frame rate. The difficulty of accomplishing sensor slewing with a

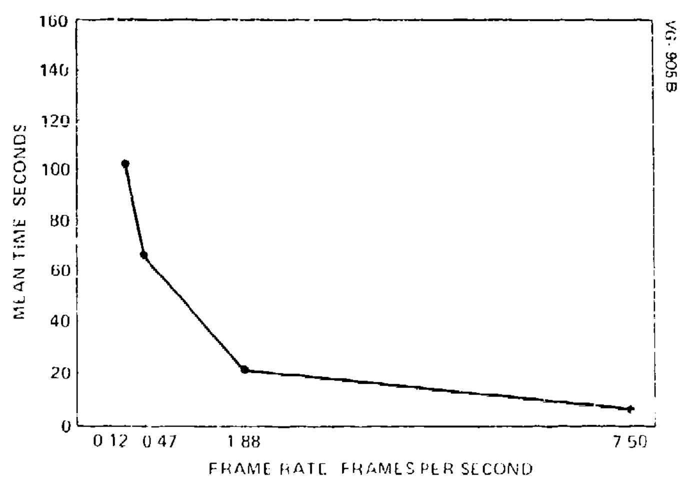

Figure 21. Effects of video frame rate on precision sensor slewing time.

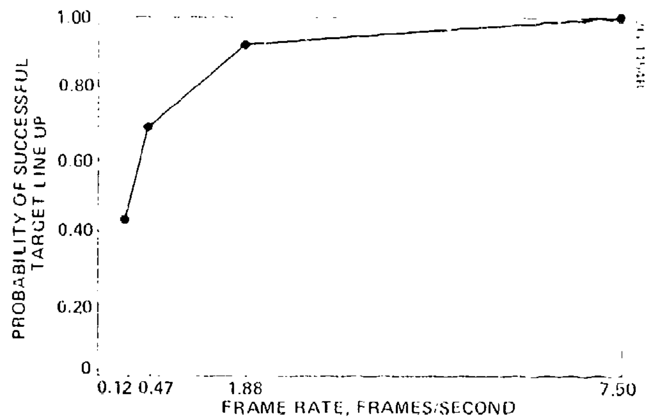

Figure 22. Effect of video frame rate on probability of successful precision sensor slewing.

very low frame rate is evidenced by the 0.42 probability of successful precision sensor slewing at the 0.12-frame per second frame rate.

A statistically reliable interaction ($p < 0.0001$) occurred between video frame rate and sensor control mode. The interaction, shown in Figure 23, was complex. At the 7.5-frame per second frame rate, the three control modes resulted in almost equivalent performance. Sensor slewing was easily accomplished at the 7.5-frame per second frame rate, regardless of the control mode used. At 1.88 frames per second and less, the superiority of the image motion compensation is very evident. Except for the initial frame delay, the image motion compensation mode resulted in no performance degradation from 7.5- to 0.12-frame per second frame rates. There was a small increase in time between the 7.5- and 1.88-frame per second frame rates for the bang-bang mode. Performance degraded rapidly at the 0.47- and 0.12-frame per second frame rates with the bang-bang mode. The continuous control mode showed considerable degradation at the 1.88-frame per second frame rate and was inferior to the bang-bang mode, except at the 7.5-frame per second frame rate, where all three control modes were equally good.

These results indicate that at a relatively high frame rate, probably between 3.75 and 7.5 frames per second, the choice of sensor slewing control modes is of little consequence. With frame rates below 2 frames per second, the image motion compensation type of control mode is clearly the best choice.

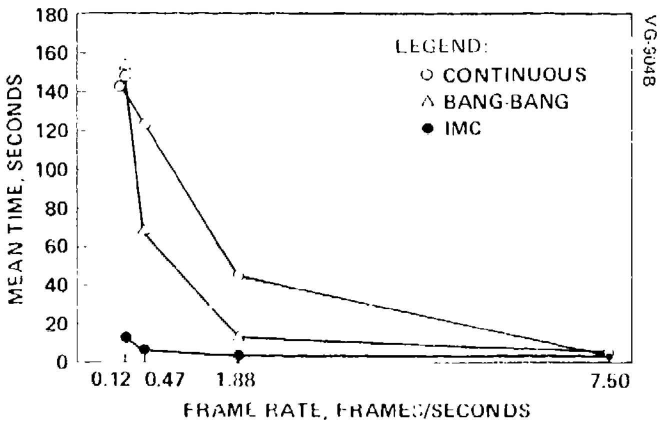

Figure 23. Interaction between video frame rate and sensor control mode for operator task time.

A bang-bang type of control mode is superior to the continuous type of control mode, but with frame rates below about 2 frames per second, the bang-bang control mode will result in rather poor operator performance.

The probability of successful precision sensor slewing results for the combinations of video frame rate and sensor control mode closely parallel the task time results, as shown in Figure 24. The 7.5-frame per second frame rate always resulted in successful sensor slewing, and successful sensor slewing was achieved at all four frame rates with the image motion compensation control mode. At the 1.88-frame per second frame rate, the bang-bang control mode also resulted in successful sensor slewing with a probability of 1.0. All other combinations of frame rates with the bang-bang and continuous control modes resulted in degraded performance. At the 0.12-frame per second frame rate, using either the bang-bang or the continuous control modes, the operators often lost the target (the target went out of the field of view as a result of over-control). This resulted in very low probabilities of successful task accomplishment – 0.08 and 0.21 for the bang-bang and continuous control modes, respectively.

Target Tracking. Two research studies of the effects of video frame rate on manual operator tracking have been conducted in support of RPV system development. In the previously cited laboratory study for the Naval Ocean

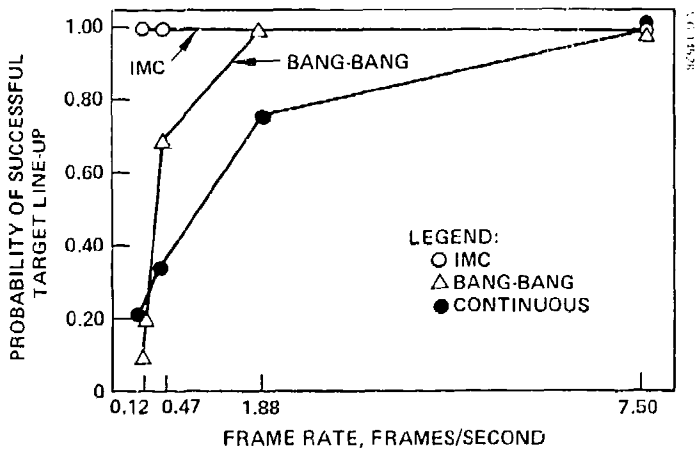

Figure 24. Interaction between video frame rate and sensor control mode for probability of successful precision sensor slewing.

Systems Center,[2] operators tracked a tank target, attempting to null out the image motion caused by the flight of a RPV with a 3-axis stabilized 2-degree field of view TV sensor. The simulated RPV was at a 762-meter altitude, flying at a speed of 50 meters per second; the initial range-to-target was 3000 meters. Sensor slewing control was with a rate control system. The operators' ability to track the tank target at frame rates of 0.94, 1.88, 3.75, 7.5, 15, and 30 frames per second was investigated.

The effect of frame rate on RMS tracking error, as shown in Figure 25, revealed that tracking error decreased rapidly as frame rate increased from 0.94 to 3.75 frames per second (10.4 to 1.5 milliradians error), a small decrease in tracking error was observed as frame rate increased from 3.75 to 15 frames per second (1.5 to 0.77 milliradians error), and tracking error remained essentially constant between 15 and 30 frames per second (0.77 to 0.70 milliradian error).

Although tracking error decreased as frame rate increased from 3.75 to 15 frames per second, the differences were not statistically reliable ($p > 0.05$). Thus a major improvement in tracking accuracy occurred as frame rate increased from 0.94 to 3.75 frames per second; increasing frame rate greater than 3.75 frames per second resulted in little if any improvement in operator tracking performance.

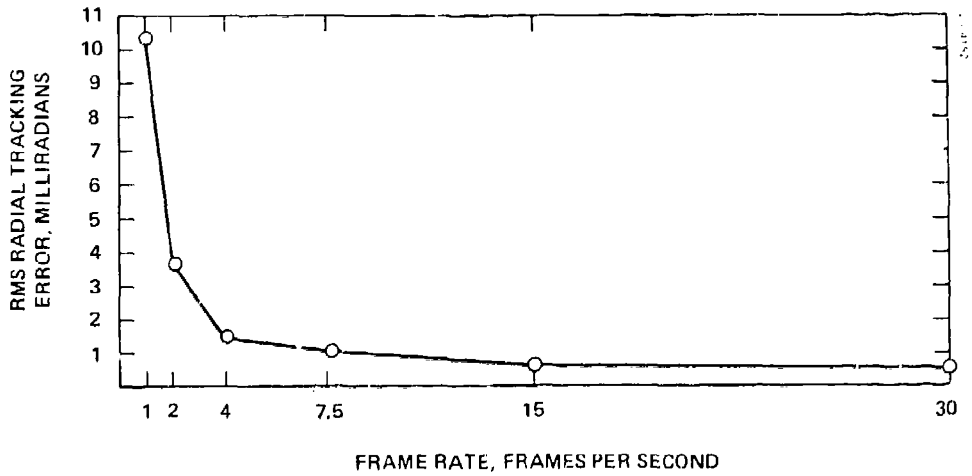

Figure 25. Frame rate effects on target tracking accuracy.

In a series of laboratory studies for the Army Electronics Research and Development Command,[9] the ability of human operators to manually compensate for the residual pointing errors that remain at the output of an automatic target tracker under conditions of data link bandwidth reduction was investigated. The research was divided into two major parts: a simulation of the environment experienced by the autotracker and a man-in-the-loop simulation of the tracking system. The first part of the simulation produced autotracker residual error data for a Southern Research Institute autotracker under a number of combinations of environmental conditions. The second part of the simulation yielded data on the magnitude of the man-in-the-loop tracking error for various system configurations. In both parts of the simulation, the target tracked was a tank located in a low clutter background.

A RPV at a range-to-target of 1.5 kilometers and an altitude of 610 meters, and a 2-degree field of view TV sensor depressed 24 degrees was simulated. The speed of the RPV was 33.1 meters per second. Autotracker residual error data were collected for 40 combinations of target-to-sun aspect, sun-to-horizon

[9] Fulkerson, D.C., Hershberger, M.L., and Scanlan, L.A., Mini-Remotely Piloted Vehicle Precision Tracking Evaluation, Hughes Aircraft Company Technical Report FR-79-27-257, U. S. Army Electronics Research and Development Command, Contract Number DAAB07-78-C-2415, September 1979.

angle, and background texture. These combinations were all possible arrangements of four sun-angles, five target aspects, and two background textures. The levels of the three variables were as follows:

Sun-to-horizon angle:	85, 65, 45, and 25 degrees from horizontal
Target-to-sun aspect:	Sun front, sun side, sun rear, sun 45° front, sun 45° rear
Background texture:	Rough and smooth.

In the final study in this series of four studies, video frame rates of 3.75, 7.5, and 15 frames per second were investigated. While increased frame rate generally reduced operator tracking error, as shown in Figure 26, the obtained performance differences among the three frame rates were not statistically reliable ($p = 0.28$). The largest improvement (20 percent in azimuth and 15 percent in elevation) occurred between the 3.75- and 7.5-frame per second frame rates.

The six studies of operator performance and video frame rate reduction are summarized in Table 3. The three studies in which target detection/recognition was investigated all indicate that operator target detection and

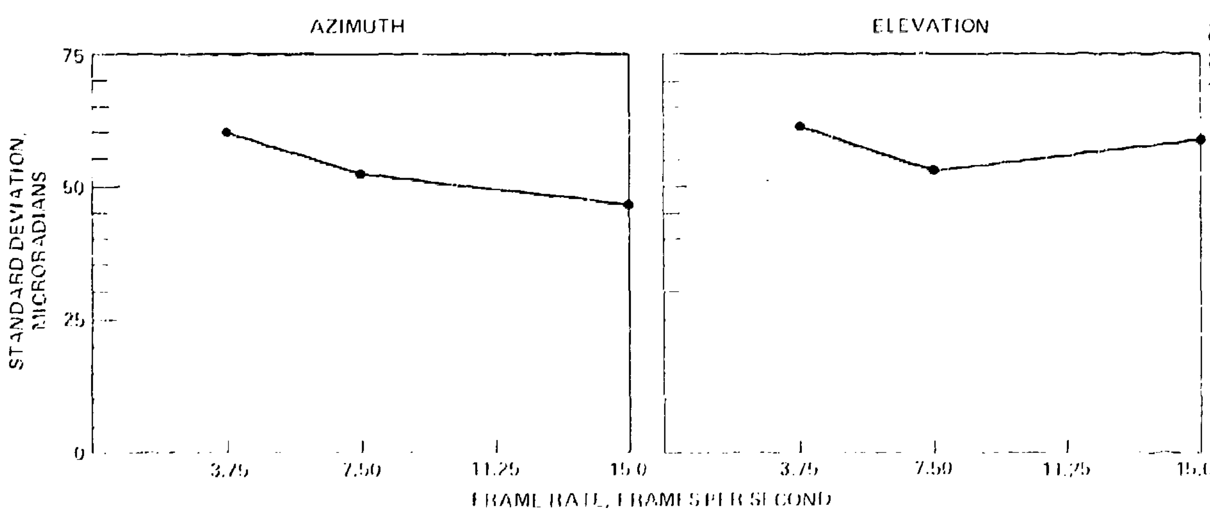

Figure 26. Effect of frame rate on tracking error.

TABLE 3. SUMMARY OF FRAME RATE REDUCTION STUDIES

Study	Frame Rates Investigated, Frames per Second	Task	Results
Self and Heckart, 1973	1, 3, 8, 24	Target Recognition	Slight trend for improved performance up to 8 frames per second. Differences not reliable.
Hershberger and Vanderkolk, 1976	0.23, 0.94, 3.75, 7.5	Target Recognition	No effect on operator performance. Initial frame period delay penalty reflected in results at 0.23 frame per second frame rate.
Swistak, 1980	1, 3, 6, 10, 30	Target Detection	No appreciable effect on operator performance.
Agin, Hershberger, and Lukosevicius, 1980	0.12, 0.47, 1.88, 7.5	Coarse Sensor Slewing	Major improvement as frame rate increased from 0.12 to 1.88 frames per second. Slight improvement between 1.88 and 7.5 frames per second.
Hershberger, 1978	0.94, 1.88, 3.75, 7.5, 15, 30	Precision Sensor Slewing	Major improvement as frame rate increased from 0.94 to 3.75 frames per second. Moderate improvement between 3.75 and 15 frames per second. No improvement between 15 and 30 frames per second.
Hershberger and Vanderkolk, 1976	0.23, 0.94, 3.75, 7.5	Precision Sensor Slewing	Major improvement as frame rate increased from 0.23 to 3.75 frames per second and no improvement between 3.75 and 7.5 frames per second with rate control mode. Performance constant from 0.23 to 7.5 frames per second with cursor designation and image motion compensation control modes.

TABLE 3. SUMMARY OF FRAME RATE REDUCTION STUDIES (Continued)

Study	Frame Rates Investigated, Frames per Second	Task	Results
Agin, Hershberger, and Lukosevicius, 1980	0.12, 0.47, 1.88, 7.5	Precision Sensor Slewing	Except for initial frame delay penalty, performance constant from 0.12- to 7.5-frame per second frame rates with image motion compensation control mode. Major improvement between 0.12 and 1.88 frames per second with continuous rate and bang-bang control modes. Moderate improvement between 1.88 and 7.5 frames per second with rate control mode. Negligible improvement between 1.88 and 7.5 frames per second with bang-bang control mode.
Hershberger, 1978	0.94, 1.88, 3.75, 7.5, 15, 30	Target Tracking	Major improvement as frame rate increased from 0.94 to 3.75 frames per second. Slight improvement as frame rate increased from 3.75 to 15 frames per second. Performance constant between 15 and 30 frames per second.
Fulkerson, Hershberger, and Scanlan, 1979	3.75, 7.5, 15	Target Tracking	Slight trend for improved performance with higher frame rate. Differences not statistically reliable.

recognition performance are resistant to major reductions of video frame rate down to 0.23 frame per second. However, frame rates below 1 frame per second will incur an initial frame period delay penalty that is reflected in a greater time or shorter range for target detection and recognition.

The single study which investigated coarse sensor slewing indicated that frame rates below 1.88 frames per second will result in substantial operator performance degradation. Only a slight coarse sensor slewing performance improvement occurred as frame rate increased from 1.88 to 7.5 frames per second.

The three studies in which precision sensor slewing was investigated all showed major performance improvement with increased frame rate up to between 1.88 and 3.75 frames per second when a continuous or bang-bang rate control mode was used. With an image motion compensation control mode, operator performance was nearly constant and equally good across all frame rates investigated from 0.12 to 7.5 frames per second. The initial frame period delay penalty, as before, was evident with frame rates below 1 frame per second.

The results from the two studies in which target tracking was investigated indicate major improvement in operator tracking performance with increased frame rate up to 3.75 frames per second. Frame rates greater than 3.75 frames per second only provided slight improvement up to 15 frames per second and no improvement for increases beyond 15 frames per second.

Sensor Resolution

Considerable research has been conducted to establish the relationship between operator target detection/recognition performance and sensor resolution. Probably the most widely used resolution criteria for tactical target detection/recognition were developed by Johnson[3] of the Army Night Vision & Electro-Optics Laboratory. Johnson's early work used single targets located in plain uncluttered backgrounds. Table 4, which summarizes that work, shows that 2 TV lines across the minimum target dimension are required for target detection and 8 TV lines are required for target recognition. Later work done at the Night Vision & Electro-Optics Laboratory extended the early Johnson working using realistic target scenes.[10] Figure 27

[10] Ratches, J.A. Lawson, W.R., Obert, L.P., Bergemann, R.J. Cassidy, T.W., and Swenson, J.M., Night Vision Laboratory Static Performance Model for Thermal Viewing Systems, U.S. Army Electronics Command, Night Vision Laboratory, ECOM-7043, April 1975.

TABLE 4. JOHNSON'S CRITERIA FOR REQUIRED RESOLUTION

Target	Resolution (in TV lines) per Minimum Dimension			
Broadside View	Detection	Orientation	Recognition	Identification
Truck	1.8	2.5	9.0	16.0
M-48 Tank	1.5	2.4	7.0	14.0
Stalin Tank	1.5	2.4	6.6	12.0
Centurion Tank	1.5	2.4	7.0	12.0
Half-Track	2.0	3.0	8.0	10.0
Jeep	2.4	3.0	9.0	11.0
Command Car	2.4	3.0	8.6	11.0
Solder (Standing)	3.0	3.6	7.6	16.0
105 Howitzer	2.0	3.0	9.6	12.0
Average	2.0 $\pm$0.5	2.8 $\pm$0.7	8.0 $\pm$1.6	12.8 $\pm$3.0

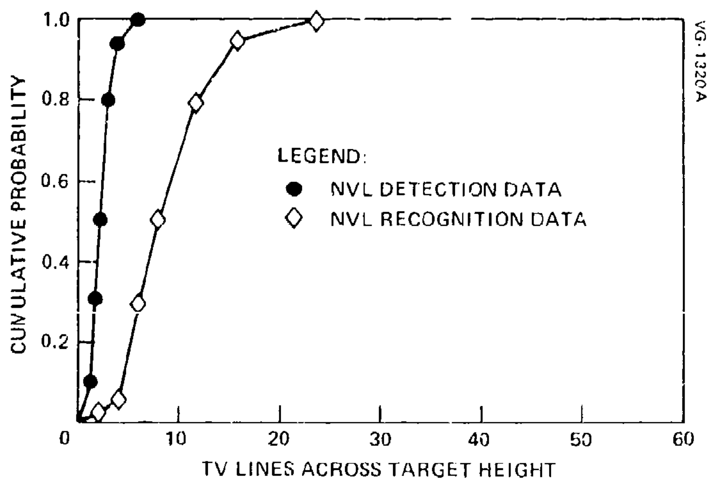

Figure 27. Night Vision and Electro-Optics Laboratory target detection and recognition curves.

shows the detection and recognition curves from that research. At the 0.5 probability level, 2 TV lines are required for detection and 8 TV lines are required for recognition. At the 0.9 probability level, 3 TV lines are

required for target detection and 14 TV lines are required for target recognition. Army RPV system performance specifications require a 0.5 probability of target detection in field environments at a 2.5 kilometer range and a 0.5 probability of target recognition at a 2.2-kilometer range. According to the criteria developed at the Night Vision & Electro-Optics Laboratory, 2 and 8 TV lines must be across the minimum target dimension when displayed to the operator for detection and recognition to occur, respectively.

R. A. Erickson and his associates at the Naval Weapons Center, China Lake, California, have done considerable research in the area of target acquisition with electro-optical raster scan systems. In a recent review paper,[11] line criteria for target acquisition with electro-optical systems are developed. Table 5, taken from that paper, summarizes the line criteria derived from prior research. The data in Table 5 indicate that 3 to 5 scan lines (1 scan line equals 1 TV line) are required to detect small targets (100 percent detection) and that 10 to 12 scan lines are required to recognize vehicle targets (80 percent recognition).

TABLE 5. LINE CRITERIA DERIVED BY ERICKSON

Task	Scan Lines Required	Performance Level, Percent Correct
Detection of small, isolated targets:		
18% Inherent contrast	3	100
7% Inherent contrast	5	100
Construction equipment detection	9	--
Ship recognition	9	80
Vehicle recognition	9	80
Building, bridge recognition	10	100
Aircraft recognition	12	80
Recognition (given detection) of 3 vehicles	12	85
Large target identification	20	—
Detection of 3 vehicles in moving imagery (time-limited search required)	20	85

[11] Erickson, R.A., Line Criteria in Target Acquisition with Electro-Optical Devices. Naval Weapons, Center, China Lake, California, NWC TP 5854, March 1976.

As part of a study of vibration effects on target recognition performance, line criteria were investigated.[12] In a static, no vibration, condition, it was found that target recognition performance plateaued (80 percent correct recognition) when 12 TV lines were across the height of tactical vehicle targets.

Several studies have investigated the effects of total system resolution on tactical target detection performance with mixed results.[13,14,15,16] In the first Oatman study,[13] 450- and 800-TV line systems (in both the horizontal and vertical dimensions) were compared. The 800-TV line system was found to result in significantly better detection of a tank target. The second Oatman study[14] compared horizontal resolutions of 300, 400, 600, and 800 lines. The 400-, 600-, and 800-line system resolutions were found to produce essentially equivalent tank detection performance, and the 300-line system was significantly poorer than the other three resolutions.

The study by Bernstein[15] compared 200-, 400-, and 600-TV line system resolutions on a tactical target detection task. The three resolutions resulted in nearly equivalent target detection performance. In the Barnes study,[16] 175- and 300-TV line resolutions were investigated for their relative impact on tactical target detection performance. Of the 10 factors investigated in the study, resolution was found to contribute only a small (2 percent) amount to the study variance.

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[12] Carel, W. L., Herman, J. A., and Hershberger, M. L., Research Studies for the Development of Design Criteria for Sensor Display Systems. Hughes Aircraft Company, Culver City, California, Report No. P75-361R, March 1976.

[13] Oatman, L.C., Target Detection using Black-and-White Television Study II: Degraded Resolution and Target Detection Probability. U.S. Army Human Engineering Laboratories, Aberdeen, Maryland, TM 10-65, July, 1965.

[14] Oatman, L.C., Target Detection Using Black-and-White Television Study III: Detection as a Function of Display Degradation, U.S. Army Human Engineering Laboratories, Aberdeen, Maryland, TM 12-65, September, 1965.

[15] Bernstein, B.R., Detection Performance in a Simulated Real-Time Airborne Reconnaissance Mission, Honeywell, Inc., Minneapolis, Minnesota, T-279 (R).

[16] Barnes, M.J., Display Size and Target Acquisition Performance. Naval Weapons Center, China Lake, California, NWC TP 6006, January 1978.

In the two Hughes studies which investigated bandwidth compression effects on RPV tactical target detection/recognition,[1,2] line criteria data are available by virtue of the performance measure being TV lines on target at detection/recognition. Figure 28 shows the results of the study[1] in which detection and recognition of single and groups of 10 targets were investigated. For the detection of single targets without bandwidth compression (6 bits per pixel), 3 TV lines across the target's height were required; detection of groups of 10 targets required 2 TV lines across the targets; target recognition required 6 TV lines across the targets' height. The line criteria are for a 0.5 probability of correct detection/recognition.

Line criteria taken from the same study when bandwidth compression was present are shown in Figures 29, 30, and 31. For a RPV system with 1.6-bit per pixel compression, (the current RPV system design uses 2.0-bit per pixel compression) 2 TV lines are required for detection of groups of 10 targets, 4 TV lines are required for detection of single targets, and 8 TV lines are required for target recognition. The above line criteria are also for a 0.5 probability level.

In the second Hughes study,[2] TV lines on target at recognition were measured, and it was found that 8 TV lines across the target height were required for bandwidth compressions from 6 to 2 bits per pixel.

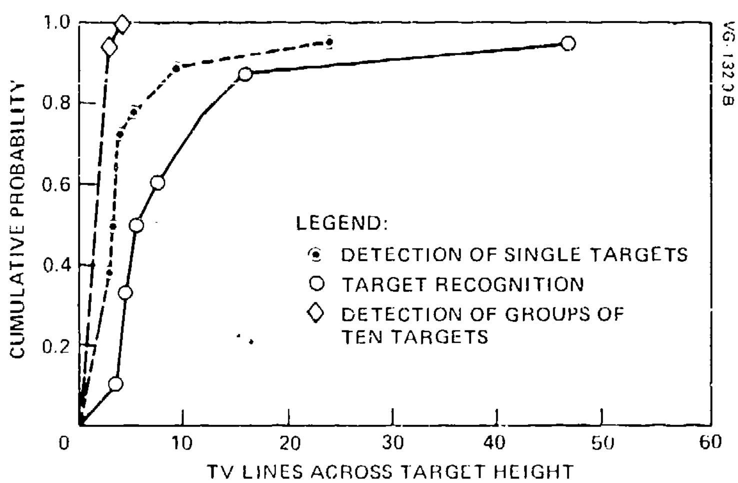

Figure 28. Target detection and recognition line criteria.

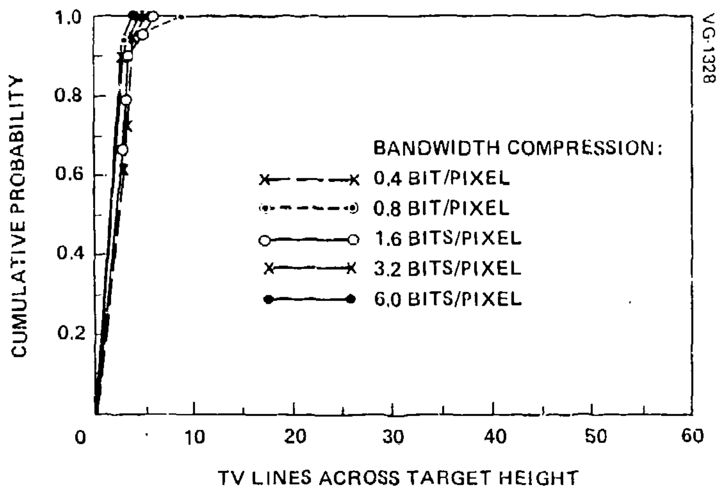

Figure 29. Performance curves for detection of groups of 10 targets.

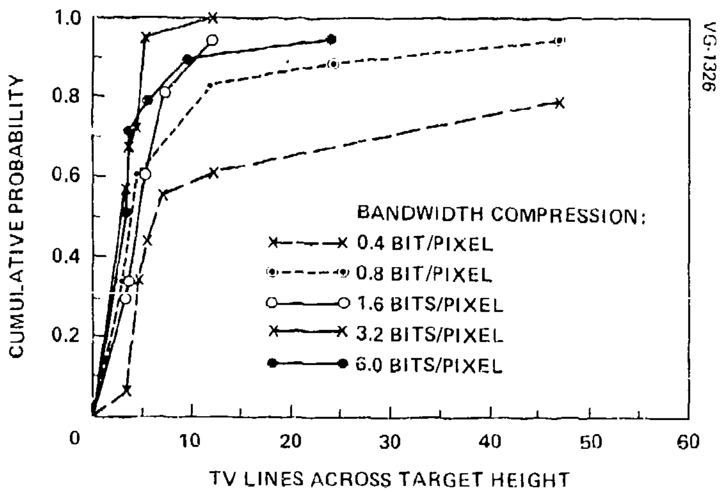

Figure 30. Performance curves for detection of single targets.

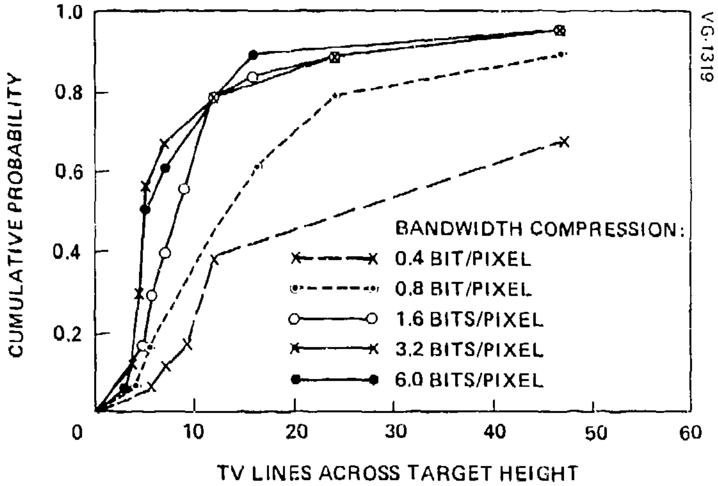

Figure 31. Performance curves for target recognition.

The research on video resolution requirements for tactical target detection and recognition described above is summarized in Table 6. The data from the studies are generally quite consistent with regard to resolution requirements for tactical detection and recognition. Target detection performance is rather insensitive to sensor resolution, requiring only 2 to 3 TV lines across the target's minimum dimension (usually the height of the target) at a 0.5 probability level. With 2.0-bit per pixel compression, the line criteria may increase to 3 TV lines for groups of targets and 4 TV lines for single targets. The number of TV lines across a target's height required for recognition to occur range from 6 to 8, depending on the probability level and the amount of compression. For a 2-bit per pixel compression system and a 0.5 probability level, the research data indicate that 8 TV lines across a target's height are required.

Sensor Field of View

For operator detection and recognition of tactical targets, the driving requirement for specification of sensor field of view is the number of sensor resolution lines that must be on the target. Given this requirement, and the desired detection and recognition range, the field of view can be specified. From the preceding discussion of sensor resolution, it was concluded that with

TABLE 6. SUMMARY OF RESOLUTION STUDIES

Study	Task/Condition	Results
Johnson, 1958	Detection, orientation, recognition, and identification of targets in uncluttered backgrounds	2 TV lines required for detection at $P_{.5}$ 8 TV lines required for recognition at $P_{.5}$
Ratches, Lawson, Obert, Bergemann, Cassidy, and Swenson, 1975	Line criteria derived from NVL field and laboratory studies	2 TV lines required for detection at $P_{.5}$ 8 TV lines required for recognition at $P_{.5}$
Erickson, 1976	Line criteria derived from laboratory studies	3-5 TV lines required for detection at $P_{1.0}$ 10-12 TV lines required for recognition at $P_{.8}$
Carel, Herman, and Hershberger, 1976	Recognition of tactical targets	12 TV lines required at $P_{.8}$
Oatman, 1965a	Detection of tank with 450- and 800-TV line systems	800-line system produced significantly higher performance.
Oatman, 1965b	Detection of tank with 300-, 400-, 600-, and 800-TV line systems	300-TV line system significantly poorer than other systems. No differences among other systems.
Bernstein, No date	Detection of tactical targets with 200-, 400- and 600-TV line systems	No appreciable differences among the three system resolutions
Barnes, 1978	Detection of tactical targets with 175- and 300-TV line systems	System resolution had small impact on detection performance

TABLE 6. SUMMARY OF RESOLUTION STUDIES (Continued)

Study	Task/Condition	Results
Agin, Hershberger, and Lukosevicius, 1980	Detection and recognition of single targets and groups of 10 targets in cluttered backgrounds	Line criteria without compression: • 3 TV lines for single targets at $P_{.5}$ • 2 TV lines for groups of ten targets at $P_{.5}$ • 6 TV lines for recognition at $P_{.5}$ Line criteria with 2 bits per pixel compression: • 4 TV lines for single target detection at $P_{.5}$ • 3 TV lines for detection of groups of 10 targets at $P_{.5}$ • 8 TV lines for recognition at $P_{.5}$
Hershberger, 1978	Recognition of tactical targets in low clutter backgrounds	8 TV lines required at $P_{.9}$ for 2 bits per pixel compression

a 2-bits per pixel element compression system 3 TV lines across a target's height are required for detection of groups of targets, 4 TV lines are required for detection of single targets, and 8 TV lines are required for target recognition. To meet these line criteria at a 2.5-kilometer detection range and a 2.2-kilometer recognition range required by Army RPV performance specifications, the sensor fields of view must not exceed:

8.4 degrees for detection of groups of targets

6.3 degrees for detection of single targets

3.6 degrees for target recognition.

These field of view requirements are based on: 1) a 2.3 meter high target, 2) a 480-TV line vertical sensor resolution, 3) 3-, 4-, and 8-TV line criteria for detection of groups of targets, detection of single targets, and recognition of targets, respectively, and 4) required detection and recognition ranges of 2.5 and 2.2 kilometers, respectively. The current RPV system design which provides discrete fields of view of 20, 13.3, 7.2, 4.8, 2.7, and 1.8 degrees will satisfy the requirements. For target detection and recognition, the operator should use the 7.2-degree field of view to search for and detect groups of targets and the 2.7-degree field of view to recognize the targets. Both U.S. Army and Air Force military operations analyses indicate that Soviet military operations will not deploy isolated single tactical targets. Therefore selection of the RPV search mode field of view should be based on requirements for detection of groups of targets, not single targets.

While line criteria place constraints on the maximum allowable sensor field of view to detect targets and it could be argued that smaller fields of view would improve detection performance, the search task is made more difficult with small fields of view, because the likelihood of targets occurring in the instantaneous displayed field of view decreases as field of view is reduced. Thus small fields of view will either require the operator to pan (slew) the sensor to search a larger area or the RPV flight time must increase to cover a given search area.

Operator controlled sensor panning has been shown to be sensitive to sensor field of view with larger fields of view providing superior search performance.[1] Figures 32 and 33 show the superior search performance with increased sensor field of view when operators were required to pan the sensor to search for targets and the target was easily detectable at all fields of view. For target search and detection the field of view should be sized to satisfy line criteria based on system performance requirements. Making the field of view larger will result in too few resolution lines on targets, degrading target detection performance; making it smaller will either degrade operator target search performance or increase RPV flight time to search an area.

The larger RPV fields of view, 20 and 13.3 degrees, would be used during artillery missions when a large field of view is needed to locate artillery bursts for burst correction. While the tradeoff between field of view and resolution for visual detection of an artillery burst is not well known, the relatively large size of the burst and the motion of the burst due to

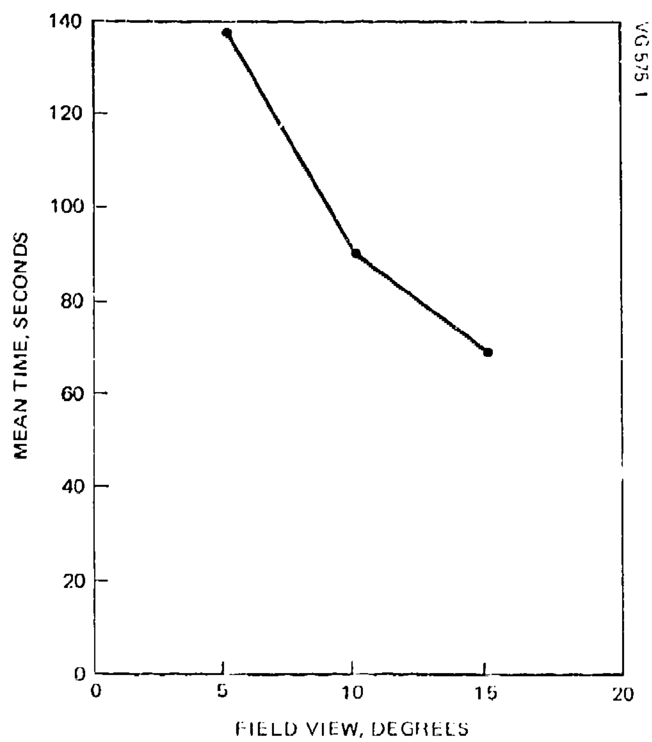

Figure 32. Effect of sensor field of view on target search and detection time.

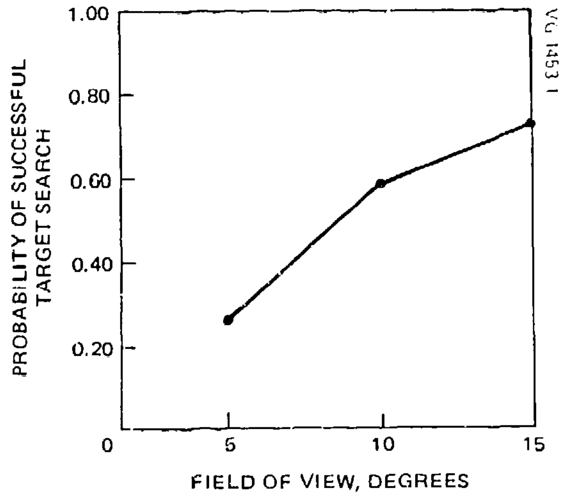

Figure 33. Effect of sensor field of view on the probability of successful target search and detection.

explosive forces and wind should result in an artillery burst being easily detectable with the larger RPV fields of view, assuming there is adequate burst-to-scene background contrast.

The smallest RPV field of view, 1.8 degrees, would be best for target tracking when continuous precision laser designation is required. The advantages of a large displayed image scale factor provided by small fields of view and electronic zoom was demonstrated in a recent study of RPV autotracker/operator precision tracking.[9] In that study, electronic zoom was found to significantly decrease operator tracking error, as shown in Figure 34. The forcing function the operators tracked was the residual error output of a Southern Research Institute contrast-centroid, adaptive gate autotracker. The simulated TV sensor field of view was 2 degrees diagonal.

Sensor Video Truncation

A reduction of video bandwidth can be achieved by transmitting less than the full sensor field of view. In effect, the video scene is truncated and the number of transmitted bits in either or both the azimuth and elevation sensor dimensions is reduced, thereby reducing the video bandwidth. In the current Army RPV system design, video truncation up to 8:1 in the azimuth

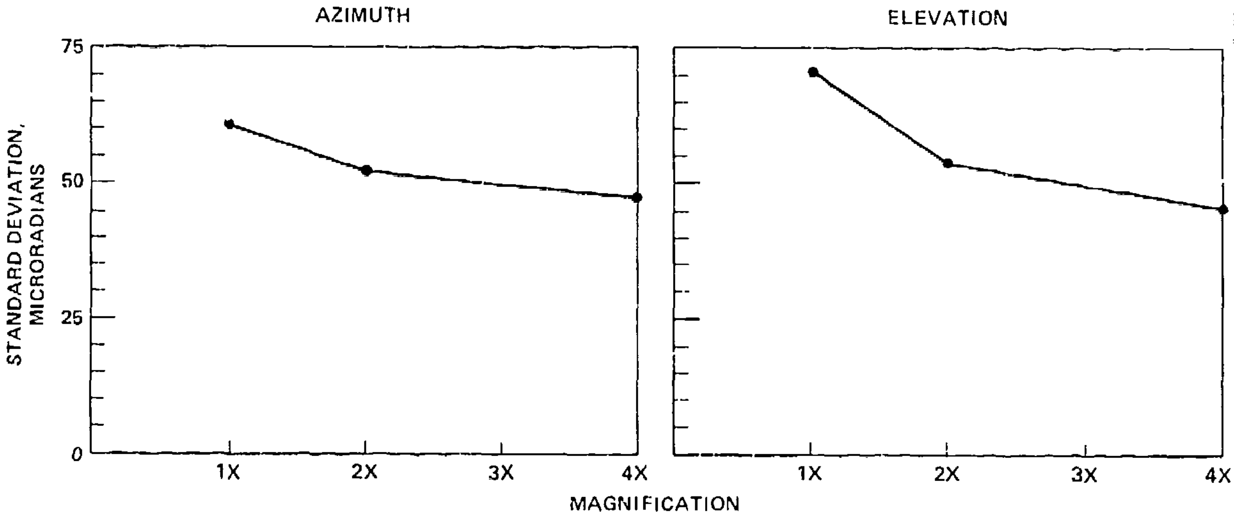

Figure 34. Effect of electronic zoom on tracking error.

dimension and 4:1 in the elevation dimension exists. This provides a maximum 32:1 bandwidth reduction for use in a high jamming environment. The literature search failed to uncover any data on the effects of video sensor truncation on operator target acquisition performance. Therefore the possible effects of video truncation can only be speculative at this time.

Since the largest possible sensor field of view compatible with resolution line criteria is desired for operator target search and detection, video underscan is not advisable during these RPV operations, because the effective field of view transmitted and displayed to the operator would be reduced. Similarly, video truncation should not be used during the early stages of artillery burst correction, because a large field of view is required to minimize the need for operator sensor slewing to locate the artillery bursts. The best use of video truncation would appear to be during target tracking operations when scene background information and target search are not important. In fact, video truncation coupled with display electronic zoom can improve operator tracking performance as demonstrated in the previously cited study[9] of RPV autotracker/operator precision tracking.

Potential video truncation problem areas to watch for include: field of view switching accuracy, truncation of part of the target, and degradation of video image quality with display electronic zoom. If the operator selects

a 1.8-degree field of view and an antijam mode with video truncation, a large field of view switching error could cause the target to be outside the effective displayed field of view. While this is a potential problem, it is anticipated that system field of view switching will be accurate enough such that the target will be in smallest 1.8-degree field of view with maximum truncation. It is also possible that a large operator target designation error in a large field of view could cause the target to be outside the effective displayed field of view of a small truncated sensor field of view. This possibility can be largely avoided if the autotracker is engaged and the target is near the boresight of the sensor prior to selecting a small truncated field of view.

Under certain conditions of sensor field of view, video truncation, electronic zoom, and target size, it is possible that the complete target would not be displayed, which could cause problems with the autotracker because of a lack of target-to-background contrast or with the operator because the complete target signature is not displayed thereby disrupting the operator's ability to locate the desired target aimpoint. The displayed ground coverage of a 1.8-degree sensor field of view at a 2-kilometer slant range to target with no video truncation is 37.7 meters vertical by 50.2 meters horizontal. Most tactical military targets do not exceed a length of 7.5 meters and a height of 3 meters. Table 7 shows the amount of displayed ground coverage of a 1.8-degree sensor field of view with 1:1 (no truncation), 2:1, 4:1, and 8:1 truncation.

TABLE 7. DISPLAYED GROUND COVERAGE WITH VIDEO TRUNCATION

Truncation	Displayed Ground Coverage, Meters	
	Horizontal	Vertical
1:1	50.2	37.3
2:1	25.1	18.8
4:1	12.6	9.4
8:1	6.3	4.7

Comparing the values in Table 7 with the 7.5-meter maximum target dimension, it can be seen that the displayed coverage is less than the target at the 8:1 truncation in both the horizontal and vertical sensor field of view coordinates. However, the current RPV system design has a maximum 4:1 truncation in the vertical coordinate; therefore, the only situation during which video truncation would result in part of the target being truncated is a large target, e.g., a tank or large truck oriented broadside to the sensor with 8:1 horizontal (azimuth) truncation. Under such circumstances 19 percent of the target would be truncated. The impact of the truncation on system performance, which would only occur when the smallest 1.8-degree field of view and the highest antijam level have been selected, is unknown.

The third potential problem area, that of image quality degradation by a large displayed scale factor with electronic zoom, is, like video truncation, relatively unexplored, and definitive data on the effects of electronic zoom on operator visual task performance could not be found. The visual effect of electronic zoom is an increased visual subtense of digitally processed sensor video picture elements. With a very large picture element subtense, the image can lose its coherency. A good example of the phenomenon is the painting by Salvador Dali "Lincoln in Dalivision." Viewed from distances of about 10 feet or less the picture looks like an abstract checkerboard of colored squares. Viewed from distances of about 15 feet or greater the face of Abraham Lincoln is clearly discernable.

The current RPV system provides 1X, 2X, or 4X electronic zoom. The operator can either have (2X or 4X) or not have (1X) electronic zoom under video truncation conditions. The value of 2X or 4X electronic zoom is automatically selected in the Army RPV. With the 7.2-inch vertical by 9.6-inch horizontal raster size of the RPV Mission Payload Operator's TV monitor and with an assumed 20-inch operator viewing distance, the video image will subtend 19.8 by 25.6 degrees (vertical by horizontal). With the 480 by 640 quantized picture element system resolution, the displayed spatial frequency of the video data will be 12.5 cycles per degree with no electronic zoom, 6.2 cycles per degree with 2X electronic zoom and 3.1 cycles per degree at 4X electronic zoom. The visual modulation sensitivity function is optimum at about 6 to 8 cyles per degree. Thus the 2X electronic zoom should be near optimum with

regard to visual modulation sensitivity, and the 1X (no electronic zoom) and 4X electronic zoom, while not optimum, should not result in a substantial departure from the optimum visual modulation sensitivity response.

An example of a TV sensor target scene at 1X, 2X, and 4X electronic zoom is shown in Figures 35, 36, and 37. The three figures are shown at full scale for the Mission Payload Operator's TV Monitor; the target scene represents a 1.8-degree diagonal sensor field of view and a 2-kilometer slant range to target. From this single example, one would conclude that electronic zoom will not cause a loss of image coherency at 2X electronic zoom. At 4X electronic zoom the blockiness of the image is readily apparent. The effect of this blockiness on operator target designation and tracking performance is not known.

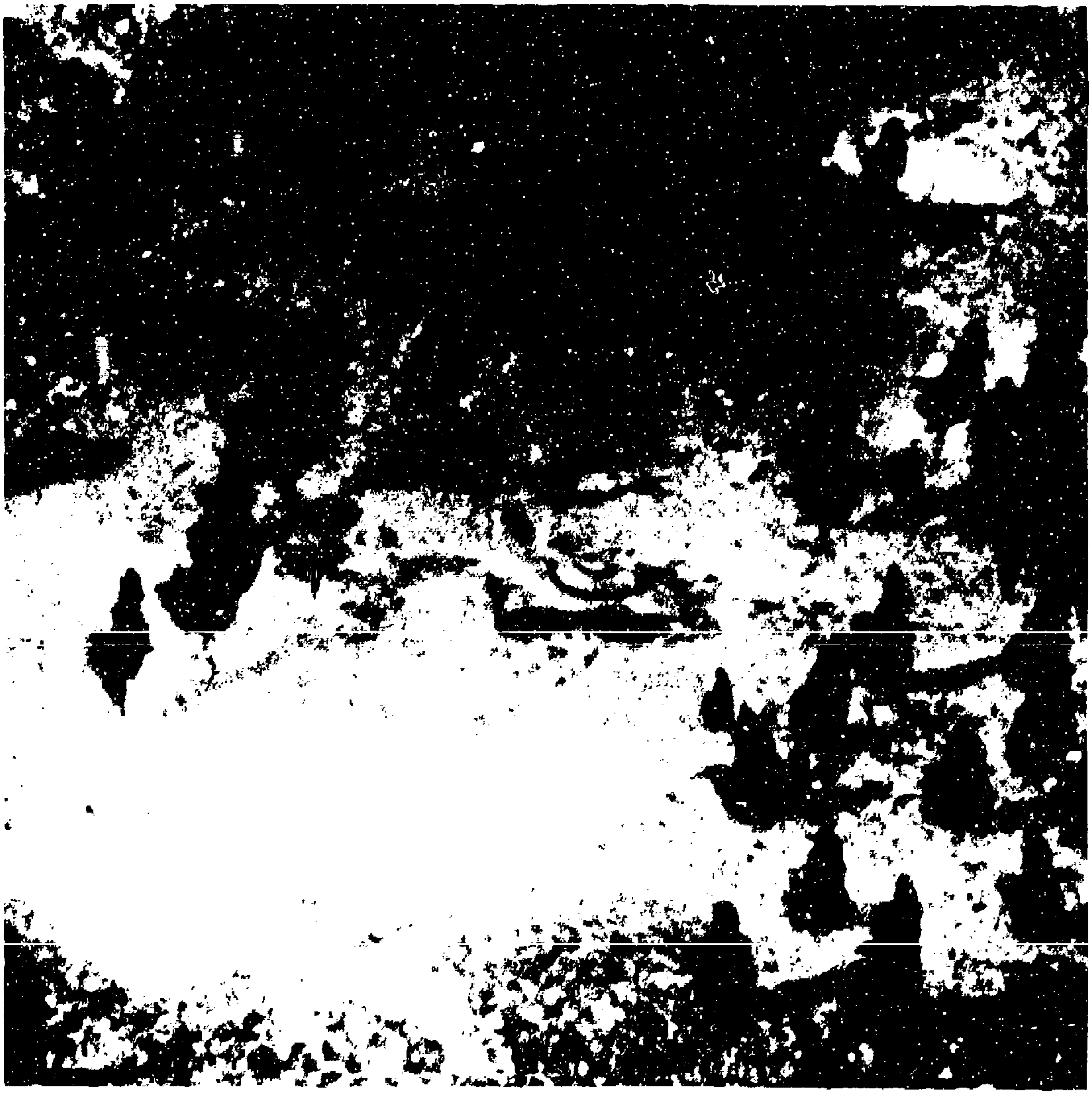

Figure 35. Target scene with 1X electronic zoom at 2-kilometer range and 1.8-degree sensor field of view.

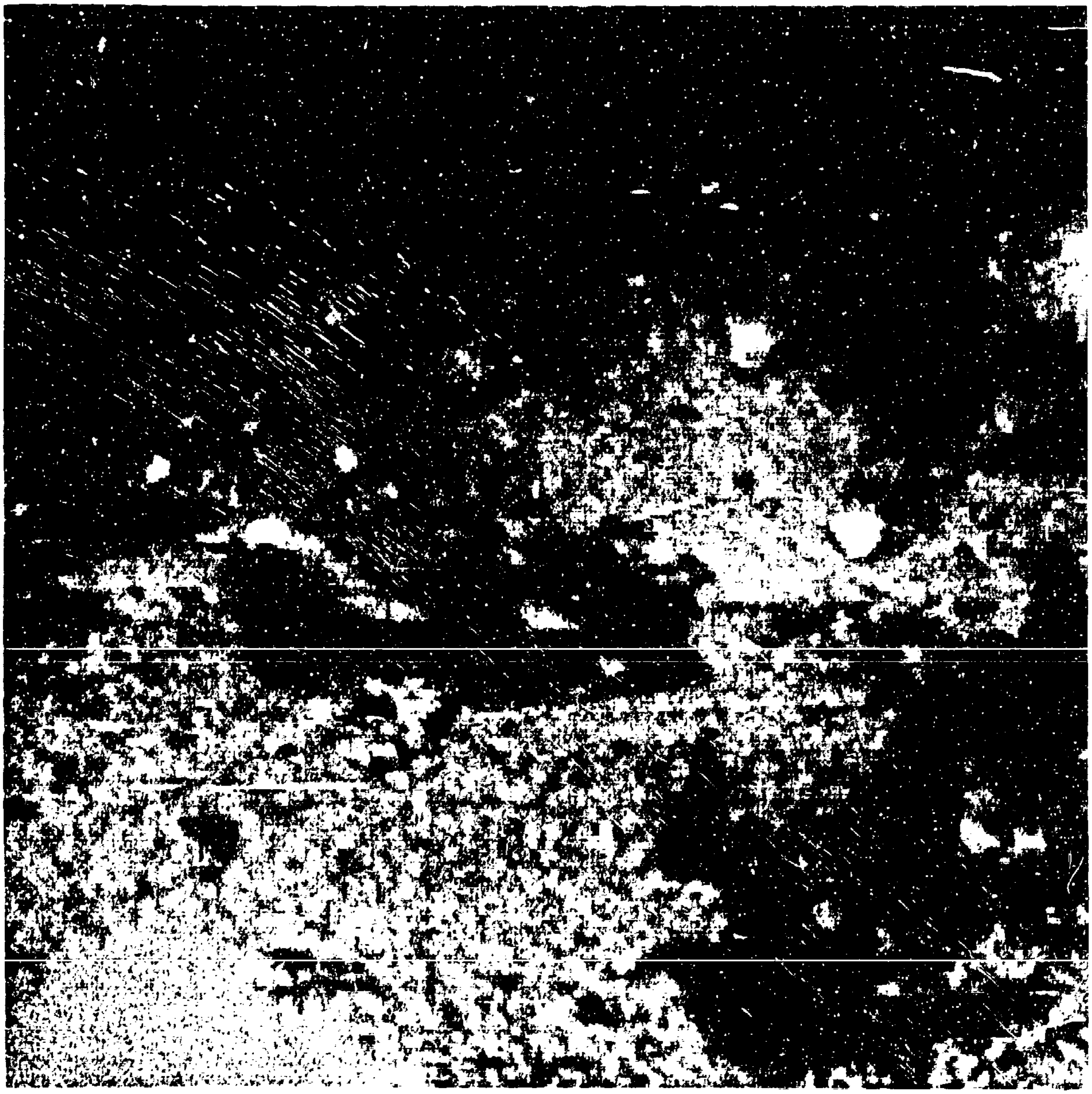

Figure 36. Target scene with 2X electronic zoom at 2-kilometer range and 1.8-degree sensor field of view.

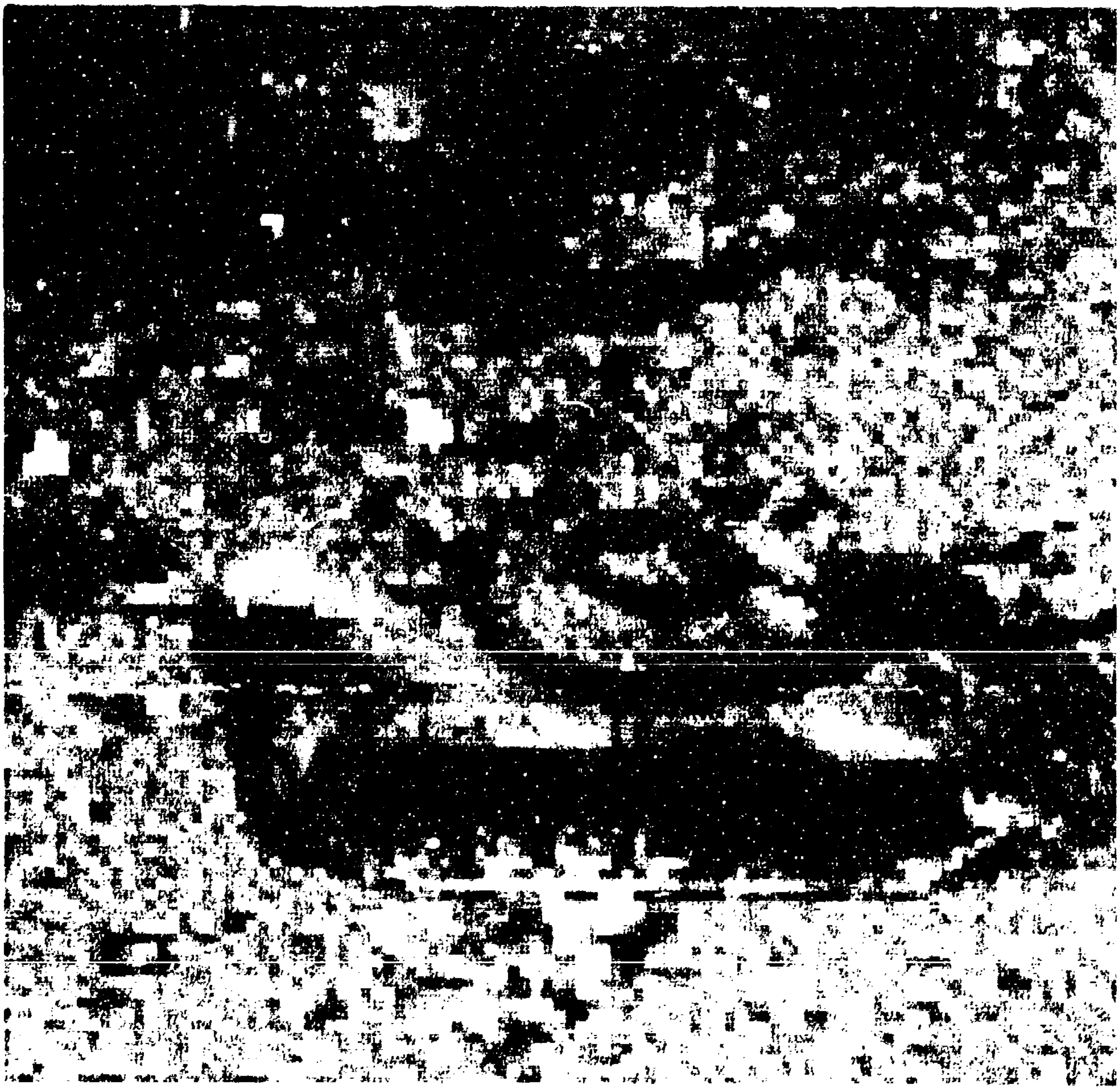

Figure 37. Target scene with 4X electronic zoom at 2-kilometer range and 1.8-degree sensor field of view.

SECTION 3

RPV MISSIONS AND TASK DESCRIPTIONS

The mission of the Army RPV system is to conduct target acquisition, designation, and aerial reconnaissance. The RPV mission consists of five primary mission elements which support combat elements of U.S. Army divisions:

- Target acquisition — detect, recognize, identify, and locate targets
- Target designation — provide reference source for laser-guided munitions
- Artillery adjustment — provide data for engaging targets with indirect-fire weapons
- Reconnaissance — obtain information about enemy activities and resources
- Damage assessment — obtain battle-damage information.

A deployed RPV system (Section) contains 13 personnel, seven vehicles, and three trailers. The breakdown of these personnel and equipment is as follows:

- Personnel

  Section Commander

  Section Chief

  Launch and Recovery Team Chief

  Senior Payload Operator and Payload Operator (2 total)

  Senior Air Vehicle Operator and Air Vehicle Operator (2 total)

  Ground Systems Mechanic

  Air Vehicle Mechanic

  Crewmen (3)

  Power Mechanic

- Vehicles

  Commander's (M882)

  Launcher Subsystem (LS)

  Ground Control Station (GCS)

  Air Vehicle Handler (AVH)

  Cargo Truck (CT)

  Maintenance Shelter (MS)

  Recovery Subsystem (RS)

- Trailers

  Remote Ground Terminal (RGT)

  Generators (2).

A typical deployment of vehicles and trailers as envisioned by the Lockheed Missiles and Space Company is shown in Figure 38.

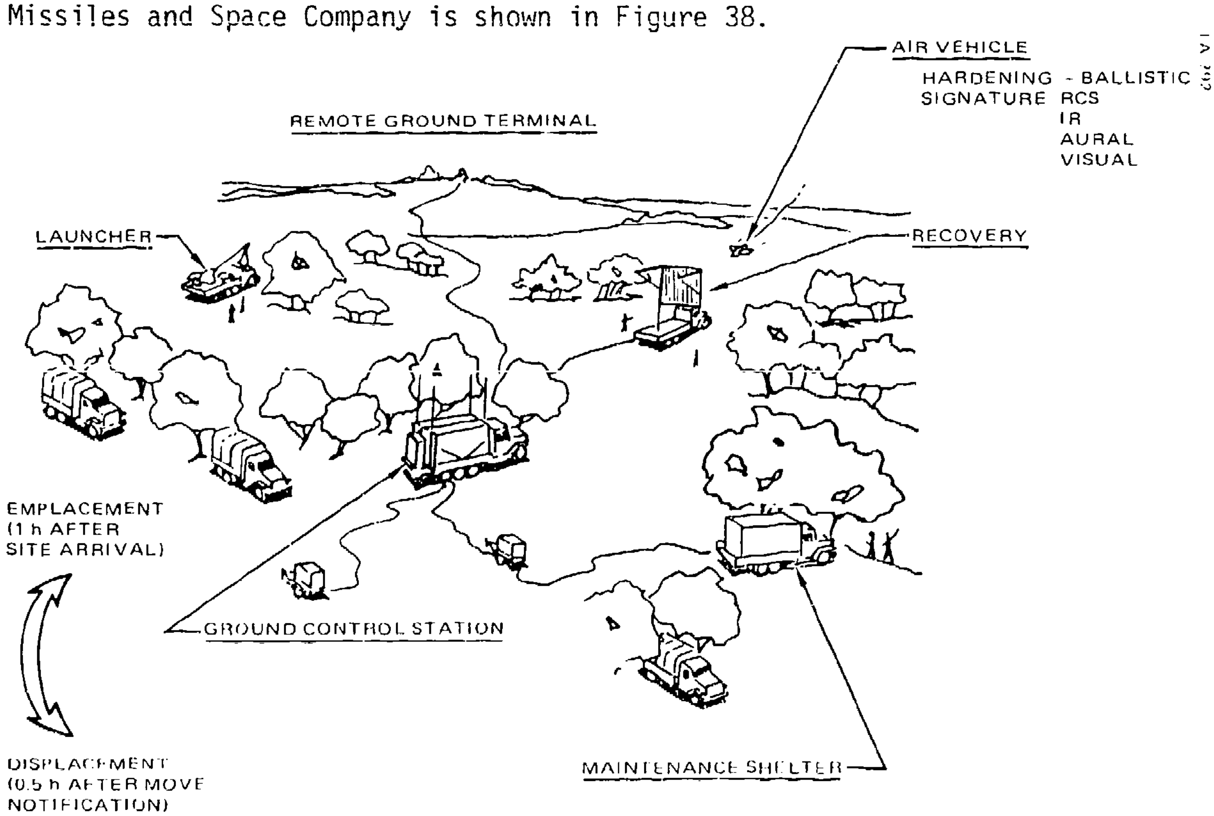

Figure 38. Field deployment of RPV system.

There are three primary RPV system operations: emplacement, mission operations, and displacement. Figure 39 shows a top level system functional flow of RPV system operations. In this report, we are primarily concerned with mission operations, specifically mission payload operations to accomplish target acquisition, designation, and aerial reconnaissance. These operations are largely accomplished through and controlled by the Ground Control Station that houses the Mission Commander, the Air Vehicle Operator, and the Mission Payload Operator. A cutaway view of the truck-mounted Ground Control Station is shown in Figure 40. The Mission Payload Operator (MPO) is the principal RPV system operator who controls the mission payload system to accomplish the target acquisition, designation, and aerial reconnaissance mission operations. A brief description of the MPO's tasks follows.

For the Misssion Payload Operator, a RPV mission will start with a mission briefing given by the Mission Commander (MC). This will be accomplished at a mission planning facility in the RPV Ground Control Station (GCS). Map and targeting data will be the primary information given to the MPO. The map will show the RPV flight plan and the target area; the targeting data will be extracted from a FRAG received at the GCS. The MC will brief the MPO and then the MPO will study the mission planning data prior to manning the Mission Payload (MP) Control and Display Console. When the MPO seats himself at the MP console, he will setup and checkout the system.

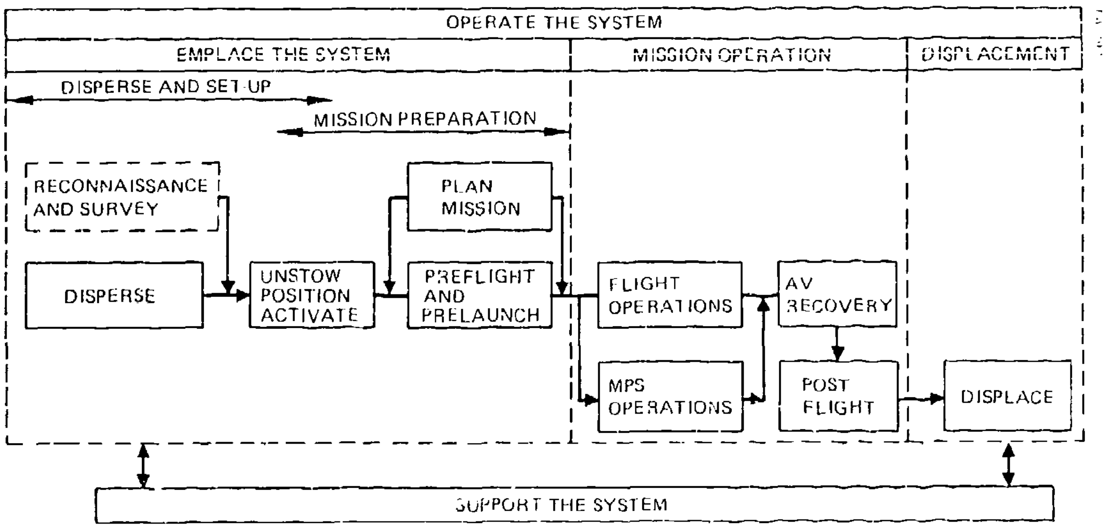

Figure 39. Top level RPV system operations.

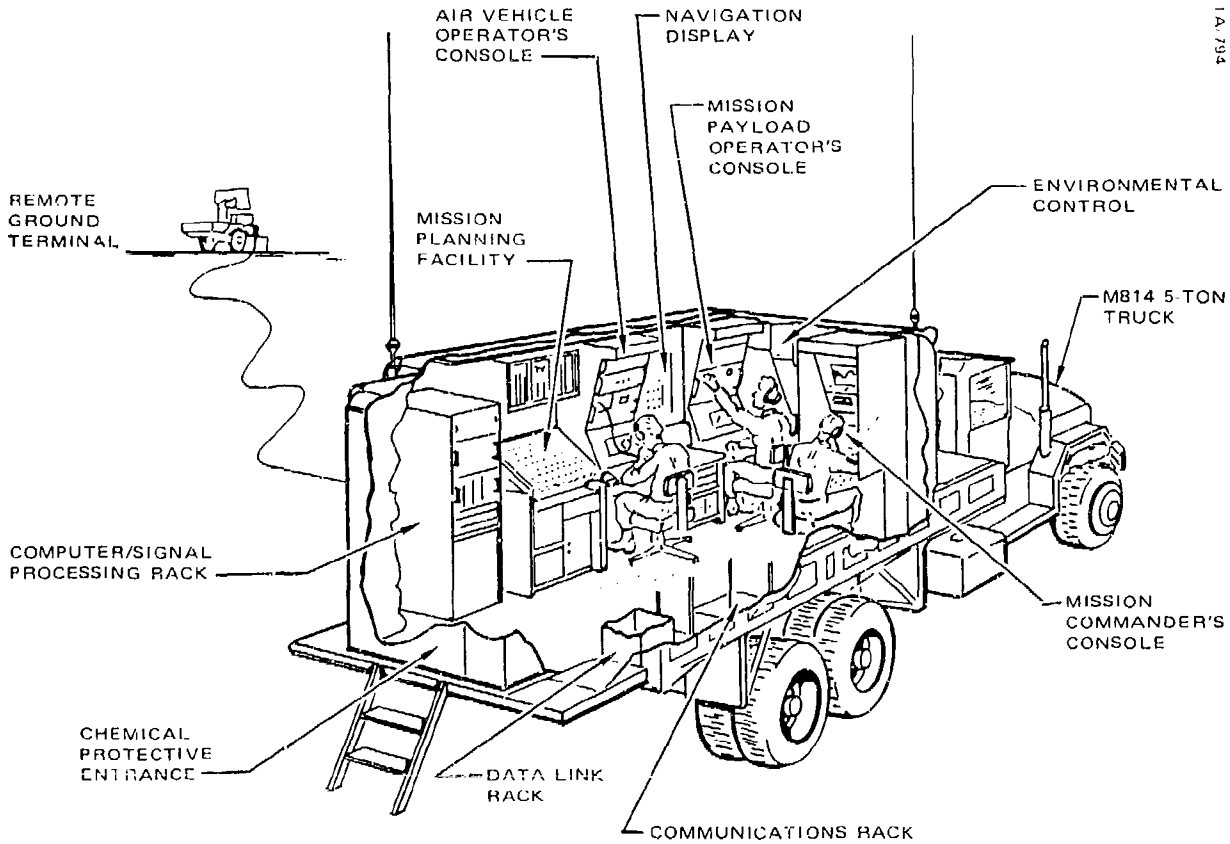

Figure 40. RPV ground control station.

The MPO will have minimal task load during the vehicle launch and en route navigation mission phases. MPO target acquisition tasks start with target search in which the MPO will be viewing wide field of view video of the target search area. The video will be dynamically displayed in concert with the speed of the vehicle and the video frame rate. Sensor depression angle is fixed during target search. When the MPO detects what he thinks is a target, he will slew the sensor to position the suspected target under a laser aim-point reticle in the center of his video display using a joystick control and select a narrow field of view. As soon as the narrow field of view video is displayed, the operator will look to see if the object he designated in the search mode is a target of interest. If the object is not a target of interest, he will return to the wide field of view. If the object is a target of interest, the MPO will request the Air Vehicle Operator (AVO) to command air vehicle orbit. When orbit has been established, the MPO will give a

command for autotracking, preparatory to either laser designation or artillery adjustment. The MPO will select the target designation or artillery adjustment mode as called for by the mission.

In laser designation, the MPO must precision designate or track the target aimpoint. The Mission Commander will give the MPO a command when he is to lase the target. In artillery adjustment, the MPO must switch back to a wide field of view. The MC will give the MPO warning before an artillery burst occurs. When the MPO detects the artillery burst, he will slew the sensor to position the burst under the laser aimpoint reticle using the joystick hand control, and depress a laser fire pushbutton to initiate burst location computation for artillery fire adjustment. Figures 41, 42 and 43 depict the reconnaissance and target acquisition/location, artillery burst correction, and target designation mission payload operations.

The control console from which the MPO performs his task is depicted in Figure 44. A larger scale drawing of the main control panel is depicted in Figure 45. A detailed analysis of MPO tasks was performed during this program. Tasks and task elements were developed for the following RPV mission payload operator functions: reviewing the mission order and flight plan, setting up the MPO station, performing reconnaissance and target acquisition/location, performing artillery burst correction, and performing target designation. The analysis, which is contained in Table 8, was based on information obtained from discussions with Army ERADCOM and Lockheed Missiles and Space Company personnel and from available Army and Lockheed RPV system documentation.

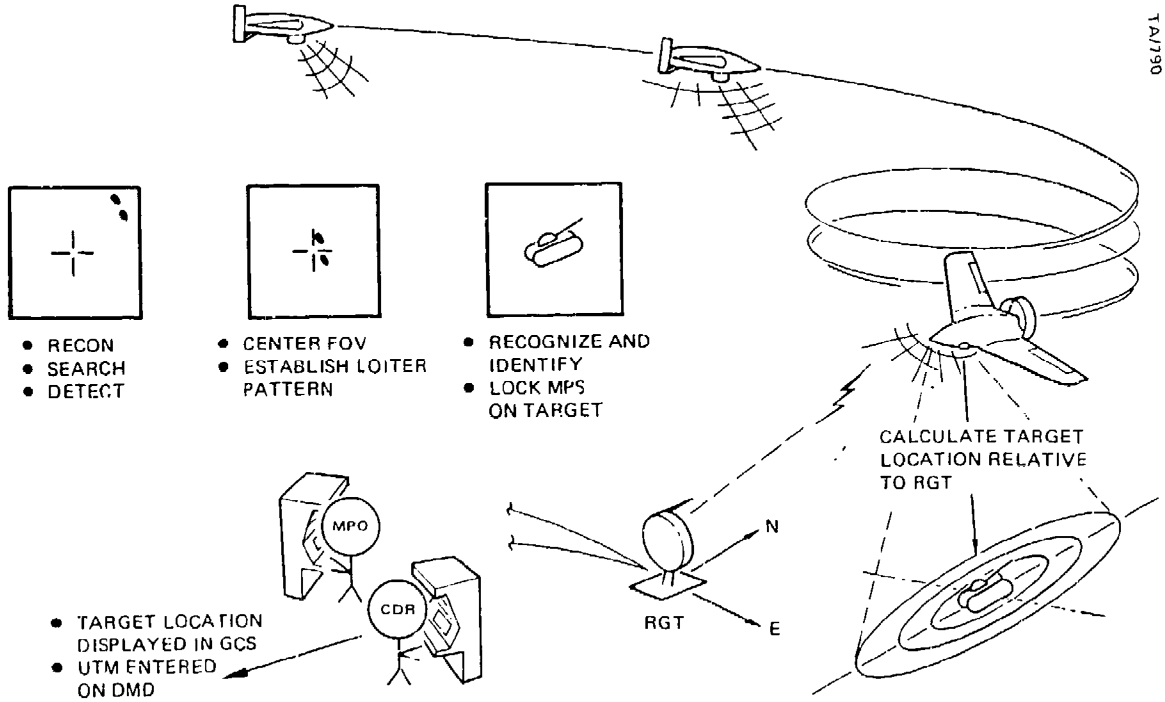

Figure 41. Reconnaissance and target acquisition/location operation.

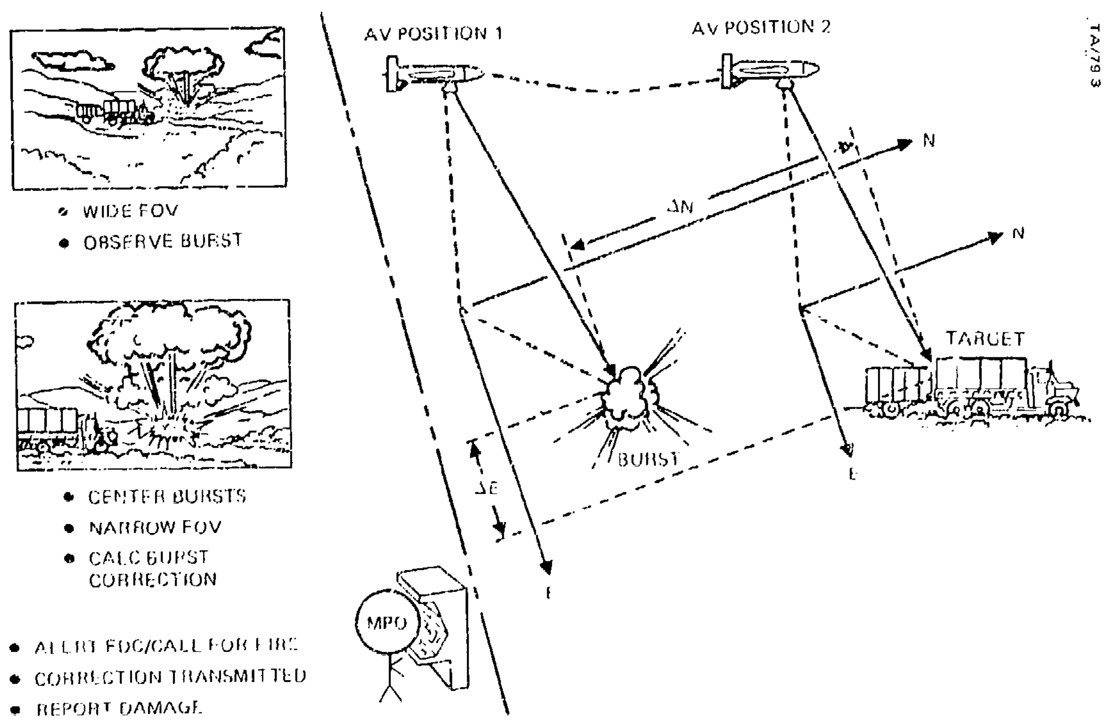

Figure 42. Artillery burst correction operation.

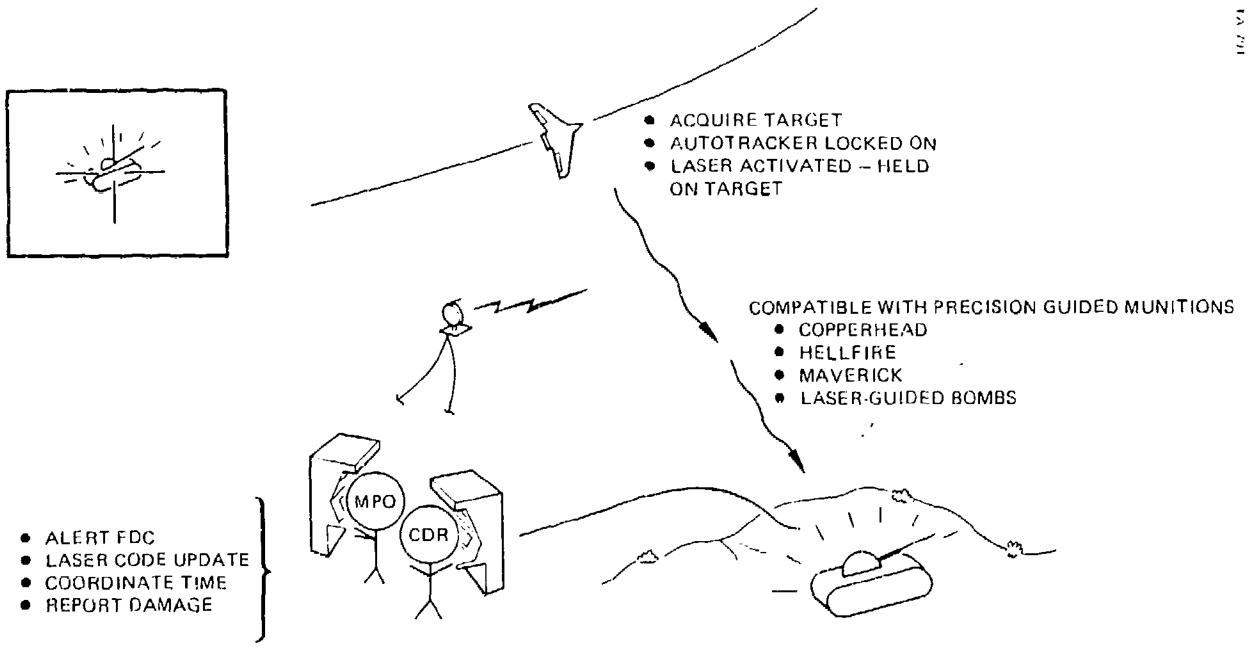

Figure 43. Target designation operation.

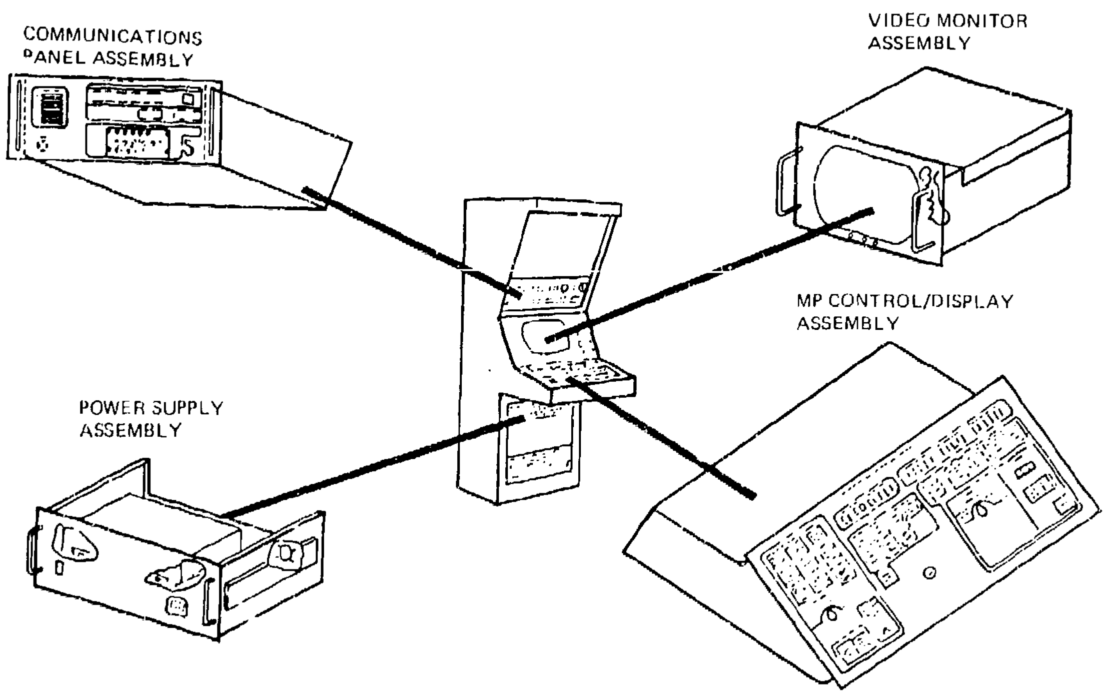

Figure 44. Mission payload operator console.

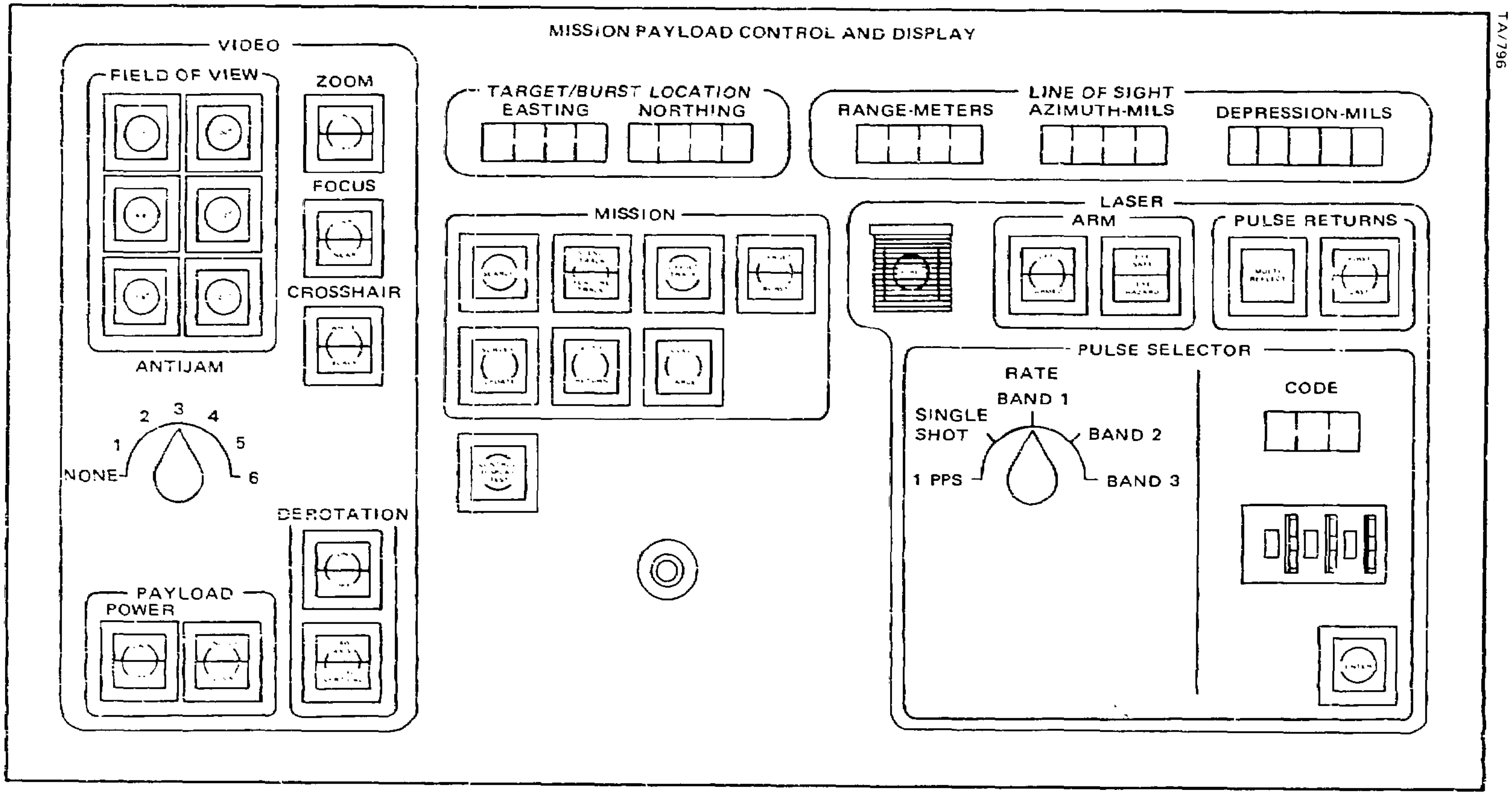

Figure 45. Mission payload operator console main control panel.

TABLE 8. RPV MISSION PAYLOAD OPERATOR TASK DESCRIPTIONS

	Task and Task Elements	Control/Display	Knowledge Requirements	Remarks Reference
1.0	Review Mission Order and Flight Plan	Navigation Display	Requires Map	Requires Map
2.0	Set up MPO Station	MPO Console	Mission Plan	
2.1	Turn Payload Power "ON"	Payload Power ON/OFF Button		
2.2	Unlock Payload	Payload Unlock/Lock Button		
2.3	Turn Derotation "ON"	Derotation ON/OFF Button		
2.4	Select Derotation "Local Vertical"	Derotation yaw axis/local vertical button		
2.5	Set Antijam to "None"	Antijam Rotary switch		
2.6	Select 7.2^{0} Field of View	7.2^{0} Field of View Button		Larger or Smaller FOV could be selected
2.7	Select Zoom "OFF"	Zoom ON/OFF Button		
2.8	Select "FAR" Range Focus	Focus Far/Near Button		
2.9	Select Crosshair Polarity	Crosshair Button		
2.10	Select "SEARCH" Mode	Mission Search Mode Button		
2.11	Set Up Laser Codes			
2.11.1	Select "BAND 1"	Laser Pulse Selector Rate Rotary Switch		
2.11.2	Enter Three Digit Code	Laser Code Thumbwheel Switch	Laser Code	

TABLE 8. RPV MISSION PAYLOAD OPERATOR TASK DESCRIPTIONS (Continued)

Task and Task Elements	Control/Display	Knowledge Requirements	Remarks Reference
2.11.3 Verify Code on LED Readout	Laser Code Readout		Readout must match code selected
2.11.4 Enter Laser Code	Laser Enter Button		
2.11.5 Repeat Steps 2.11.1 Through 2.11.5 for Bands 2 and 3			
2.12 Arm Laser	Laser OFF/Armed Button		
2.13 Select First Laser Pulse Return	Laser Pulse Return First/Last Button		
2.14 Checkout Controls/ Indicators	All Controls and Displays		
3.0 Reconnaissance and Target Acquisition/ Location			
3.1 Monitor Sensor Video	Video Monitor		
3.2 Adjust Video Brightness and Contrast	Video Monitor Brightness and Contrast Controls		
3.3 Check AV Location	Navigation Display		
3.4 Select Search Mode	Search Mode Button		

TABLE 8. RPV MISSION PAYLOAD OPERATOR TASK DESCRIPTIONS (Continued)

	Task and Task Elements	Control/Display	Knowledge Requirements	Remarks Reference
3.5	Select Cued Target Mode	Cued Target Button		Must be coord. with MC. Slews sensor to a pre-selected LOS.
3.6	Select Target Mode	Target/Burst Button		
3.7	Search Target Area	Video Monitor		
3.8	Note Noisey Video	Video Monitor		
3.9	Select Position 3 ON Antijam Control	Antijam Rotary Switch		Other positions could be selected
3.10	Check Video Quality	Video Monitor		
3.11	Detect Target	Video Monitor		
3.12	Slew Sensor to Position Target Under Laser Aimpoint Reticle	Joystick Control, Video Monitor		Light Pen Designation could be Used to Command Sensor Slew
3.13	Activate Autotracking	Scene Track/Feature Track Button		
3.14	Note Lock-On Indication	Video Monitor		Track Box on Display
3.15	Select 2.7^{o} Field of View	2.7^{o} Field of View Button		Other FOVs could be Selected
3.16	Recognize and Identify Target(s)	Video Monitor		
3.17	Request AVO to Command AV Orbit	Intercom		Orbit Command could be Automatic

TABLE 8. RPV MISSION PAYLOAD OPERATOR TASK DESCRIPTIONS (Continued)

	Task and Task Elements	Control/Display	Knowledge Requirements	Remarks Reference
3.18	Monitor Video During Transition to Orbit	Video Monitor		No Loss of Video
3.19	Inform MC of Intent to Range	Intercom		
3.20	Select Single Shot Laser	Laser Pulse Selector Rotary Switch		
3.21	Lift Guard on Laser Button	Guard on Laser Fire Button		
3.22	Fire Laser	Laser Fire Button		
3.23	Note Laser Fire DOT	Video Monitor		Dot Pulses at 3-5 PPS
3.24	Note Range to Target	LED Range Readout		
3.25	Place Guard Over Laser Fire Button	Guard on Laser Fire Button		
4.0	Artillery Burst Correction			
4.1	Monitor Autotrack on Target	Video Monitor		
4.2	Receive MC Notification of Impending Artillery Fire/Burst Correction			
4.3	Select Burst Mode	Target/Burst Button		

TABLE 8. RPV MISSION PAYLOAD OPERATOR TASK DESCRIPTIONS (Continued)

	Task and Task Elements	Control/Display	Knowledge Requirements	Remarks Reference
4.4	Select 20° Field of View	20° Field of View Button		
4.5	Wait for Artillery Fire			
4.6	Receive Notification of Artillery Fire From MC	Intercom		
4.7	Search for Artillery Burst	Video Monitor		
4.8	Detect Burst	Video Monitor		If burst not in FOV, MPO Slews sensor using joystick to search for burst.
4.9	Deactivate Autotracking	Search Mode Button		
4.10	Slew Sensor to Position Burst Under Laser Aimpoint Reticle	Joystick Control, Video Monitor		
4.11	Select 2.7° Field of View	2.7° Field of View Button		Other FOVs could be selected; use larger FOV to contain target and burst if designation is accurate enough
4.12	Slew Sensor to Center Burst Under Laser Aimpoint Reticle	Joystick Control, Video Monitor		

TABLE 8. RPV MISSION PAYLOAD OPERATOR TASK DESCRIPTIONS (Continued)

	Task and Task Elements	Control/Display	Knowledge Requirements	Remarks Reference
4.13	Activate Autotracking	Scene Track/Feature Track Button		
4.14	Note Lock-On Indication	Video Monitor		
4.15	Inform MC of Intent to Range	Intercom		
4.16	Lift Guard on Laser Firw Button	Guard on Laser Fire Button		
4.17	Fire Laser	Laser Fire Button		
4.18	Note Laser Fire Dot	Video Monitor		
4.19	Note Range to Burst	LED Range Readout		
4.20	Select 7.2^{o} Field of View	7.2^{o} Field of View		Other FOVs could be selected
4.21	Monitor Video for Next Artillery Burst	Video Monitor		
4.22	Repeat Tasks 4.8 Through 4.19 as Necessary Until Artillery Hits Target			
4.23	Assess Target Damage	Video Monitor		
4.24	Report Damage Assessment to MC	Intercom		

TABLE 8. RPV MISSION PAYLOAD OPERATOR TASK DESCRIPTIONS (Continued)

	Task and Task Elements	Control/Display	Knowledge Requirements	Remarks Reference
5.0	Target Designation			
5.1	Monitor Autotrack On Target	Video Monitor		
5.2	Note Noisey Video	Video Monitor		
5.3	Select Position 5 On Antijam Control	Antijam Rotary Switch		Other positions could be selected
5.4	Check Video Quality	Video Monitor		
5.5	Receive MC Notification of Impending Fire	Intercom		
5.6	Select 1.8^0 Field of View	1.8^0 Field of View Button		Other FOVs could be selected
5.7	Activate Zoom	Zoom ON/OFF Button		
5.8	Receive MC Command to Lase Target	Intercom		
5.9	Select Laser Band 1	Laser Pulse Selector Rotary Switch		
5.10	Slew Sensor as Necessary to Position Target Aim-point Under Laser Aim-point Reticle	Joystick, Video Monitor, Offset Track Button		Requires Offset Tracking

TABLE 8. RPV MISSION PAYLOAD OPERATOR TASK DESCRIPTIONS (Concluded)

Task and Task Elements		Control/Display	Knowledge Requirements	Remarks Reference
5.11	Fire Laser	Laser Fire Button		Laser Fire Button Held in Firing Position Until Artillery Impacts
5.12	Slew Sensor as Necessary to Maintain Target Aimpoint Under Laser Aimpoint Reticle	Joystick, Video Monitor		
5.13	Monitor Target Video for Fire Impact	Video Monitor		
5.14	Cease Laser Firing	Laser Fire Button		
5.15	Assess Target Damage	Video Monitor		
5.16	Report Damage Assessment to MC	Intercom		
5.17	Repeat Tasks 5.8 Through 5.16 for Additional Targets			

SECTION 4

RPV OPERATOR TASKS AND BANDWIDTH COMPRESSION/REDUCTION SYSTEM DESIGN

INTRODUCTION

In Section 2 of this report, the literature dealing with video bandwidth compression/reduction and operator performance was reviewed, and in Section 3 RPV Mission Payload Operator tasks were identified. In this section, recommended RPV bandwidth compression/reduction system design parameters will be developed based on the results of the literature review for the operator tasks which require the use of sensor video.

The Army RPV system design parameters which are of major potential importance to operator task performance and require the use of sensor video include: video bandwidth compression, sensor resolution, sensor field of view, sensor video truncation, video frame rate, sensor control mode, and electronic zoom. The Army RPV Mission Payload Operator tasks which may be significantly affected by these system design parameters include: target search and detection, target recognition, sensor slew control, target designation and tracking, artillery burst detection, artillery burst designation, and battle-damage assessment.

The current Army RPV system design provides seven operator selectable levels of video data rates (antijam levels) for operation in benign and jamming environments. The seven levels are based on various combinations of video frame rate, sensor resolution, and video truncation. A fixed 2-bit per pixel cosine/DPCM bandwidth compression is used at all seven data rates. The combinations of frame rate, resolution, and truncation for any particular data rate selected depend on the RPV mission/mode. There are three such mission/modes: search, artillery, and track. Table 9 gives the values of frame rate, resolution, and truncation currently provided in the RPV system design for the 21 combinations of the seven data rates (antijam levels) and the three mission/modes.

While sensor field of view and electronic zoom do not directly affect video data rate, they are important parameters that affect video image quality and operator task performance and also interact with sensor resolution

TABLE 9. RPV ANTIJAM LEVELS

Antijam Level	Data Rate, Mb/s	Frame Rate, Frames/Second	Resolution	Truncation	Mission
None	4.6	15/2	640 x 480	640 x 480	Search
	4.6	15/2	640 x 480	640 x 480	Artillery
	4.6	15	320 x 480	320 x 480	Track
1	2.3	15/4	640 x 480	640 x 480	Search
	2.3	15/4	640 x 480	640 x 480	Artillery
	2.3	15	640 x 480	320 x 240	Track
2	1.15	15/8	640 x 480	640 x 480	Search
	1.15	15/4	320 x 480	320 x 480	Artillery
	1.15	15/2	640 x 480	320 x 240	Track
3	0.576	15/16	640 x 480	640 x 480	Search
	0.576	15/4	320 x 240	320 x 240	Artillery
	0.576	15	640 x 480	160 x 120	Track
4	0.288	15/32	640 x 480	640 x 480	Search
	0.288	15/8	320 x 240	320 x 240	Artillery
	0.288	15/2	640 x 480	160 x 120	Track
5	0.144	15/64	640 x 480	640 x 480	Search
	0.144	15/16	320 x 240	320 x 240	Artillery
	0.144	15/2	320 x 480	80 x 120	Track
6	0.072	15/128	640 x 480	640 x 480	Search
	0.072	15/16	160 x 240	160 x 240	Artillery
	0.072	15/4	320 x 480	80 x 120	Track

and video truncation which determine video data rate. Similarly, sensor control does not directly affect video data rate, but it has been shown to interact with video frame rate which is a major video data rate reduction parameter [1,4]. In the following pages of this section, the recommended RPV system video image and sensor control design parameters will be developed for each of the previously identified RPV Mission Payload Operator tasks and contrasted with the current RPV system design parameters.

TARGET SEARCH AND DETECTION

For the MPO to visually search and detect tactical targets, high quality sensor video is of paramount importance. The principal RPV parameters that

determine video image quality are bandwidth compression and sensor resolution. The research on operator tactical target detection indicate that a compression level of 1.5 to 2.0 bits per picture element results in performance that is nearly equivalent to uncompressed 6-bit per picture element video [1,2,7]. It is therefore concluded that the 2.0-bit per picture element compression RPV design is a near optimum choice. Maximum data rate reduction will be achieved with minimum impact on operator target detection performance. Research data on sensor resolution requirements indicate that with 1.6-bit per picture element compression, 3 TV lines across the height of targets are required to detect groups of targets[1]. Since TV lines on target are also determined by sensor field of view and range-to-target, the selection of sensor resolution must also consider these factors. The Army RPV performance specification requires a detection range of 2.5 kilometers at a 0.5 probability of detection. To achieve the 3 TV lines on target at the 2.5-kilometer range detection, one can tradeoff sensor resolution and field of view which are directly proportional — higher resolution permits the use of larger fields of view, and larger fields of view promote greater efficiency of searching a given ground area. However, higher resolutions result in higher data rates and the resulting greater susceptibility to jamming. In effect, higher resolution allows the use of larger search fields of view but increases the data rate and hence jamming susceptibility.

The current RPV design uses a 480- by 640-element system resolution in the search mission/mode at all six antijam levels and provides six operator-selected fields of view ranging from 20 to 1.8 degrees diagonal. This is a reasonable compromise position in that maximum available system resolution is provided for target search and detection, and the operator is free to select the field of view which best meets his task demands. Based on the previous literature review and analysis of sensor field of view requirements, an 8.4-degree field of view is required to satisfy the 3-TV line criterion and 2.5 kilometer detection range requirement. A 7.2-degree field of view available in the current RPV system design best meets these requirements and is a good design choice.

Video truncation is not recommended for target search and detection, because it reduces the effective displayed sensor field of view and as a

consequence ground search efficiency is reduced. Video truncation is not used in the search mission/mode with the current RPV system design — another good design choice.

Three independent research studies have shown visual target search and detection to be insensitive to video frame rate down to 0.25 frame per second[4,6,8]. Frame rates from 15 to 0.12 frames per second are available in the RPV system design, depending on the selected antijam level. We expect the insensitivity to hold down to the 0.12 frame per second minimum RPV frame rate. Further reduction of video frame rate is possible if the interframe time interval is greater than the time it takes the RPV to fly a distance determined by the sensor field of view, sensor depression angle, RPV speed, and RPV altitude. Assuming a nominal RPV speed of 130 kilometers per hour, a 1000-meter altitude, and a 25-degree sensor depression angle, video frame rates as low as 0.026 and 0.075 frames per second with 20- and 7.2-degree sensor fields of view could be used without the flight time exceeding the interframe interval. While such very low frame rates could provide as much as an additional 4.6 times reduction of video data rate, the time to transmit a field of view scene would be quite large — 38 seconds. Furthermore the 20-degree field of view that would allow this very low frame rate is not recommended for target search and detection. The 0.075 frame per second frame rate that provides a 1.6 factor reduction in data rate compared to the current 0.12 frame per second minimum RPV frame rate, however, is worthy of consideration. A 0.06 frame per second frame rate might be considered for the RPV digital data link.

TARGET RECOGNITION

High quality sensor video is also of paramount importance for the operator to recognize tactical targets. After the MPO has detected an object which he suspects to be a target, he will select a smaller field of view that results in an increased target size and increased resolution lines across the target.

The video bandwidth compression research surveyed indicates that a cosine/DPCM 1.5- to 2.0-bit per picture element transform compression system results in minimum operator target recognition performance degradation compared to an uncompressed 6-bit per picture element system [1,2,7]. Therefore the 2.0-bit per picture element compression system currently planned for the

Army RPV will satisfy the video compression system requirements for target search, detection, and recognition.

For target recognition to occur, the displayed target size and sensor resolution lines across the target must satisfy minimum criteria that exceed the target detection criteria. As with many electro-optical sensor systems, this increase in size and resolution will be accomplished in the Army RPV by switching to a narrower sensor field of view. The review of the literature on sensor resolution, bandwidth compression, and operator target recognition performance indicated that 8 TV lines across a target's height are required to recognize targets with a 2-bit per picture element compression system at 0.5 probability of correct target recognition[1,2]. For 8 TV lines to be across a 2.3-meter target height at a 2.2-kilometer range to target, the sensor field of view should not exceed 3.6 degrees diagonal. The Army RPV system currently provides 20-, 13.3-, 7.2-, 4.8-, 2.7-, and 1.8-degree fields of view. The 4.8-degree field of view would result in 6 TV lines across the height of 2.3-meter high targets, which falls short of the 8-TV line criterion, and the 2.7-degree field of view would result in 11 lines across the height of targets. Thus the 2.7-degree field of view should be used for target recognition. While this field of view provides better target definition and therefore should improve target recognition to a 0.75 probability of target recognition, the displayed ground coverage will be reduced by about 34 percent compared to the required 3.6-degree field of view. The effect of the reduced ground coverage is that fewer targets will be contained within the target recognition field of view.

Video truncation is a possible means of reducing video bandwidth during the target recognition process if the target is centered in the sensor field of view and if the operator is interested in recognizing a single target. A 2.7-degree sensor field of view could be truncated by a factor of 20:1 in both dimensions and still contain a 7.6-meter long target. The practical feasibility of video truncation depends on the mission requirements and operational considerations beyond the scope of this analysis. The current RPV system does not use video truncation in the RPV search mode in which the target recognition function is performed.

The effects of video frame rate on target recognition are the same as described for target search and detection. Hence, the 0.12 frame per second frame rate in the current RPV system design will not degrade operator target recognition performance. In fact, there is no apparent need to transmit video while the operator is interpreting the small field of view video image containing the target that has already been transmitted. However, the required time to accomplish target recognition, once detection has occurred, is usually quite small; hence, the period of zero data rate transmission would be of a short duration.

SENSOR SLEW CONTROL, TARGET AND ARTILLERY BURST DESIGNATION, AND TARGET TRACKING

Operator tasks that require sensor pointing are primarily affected by video frame rate and sensor control mode. Sensor slew control includes: 1) coarse sensor slewing to search an area larger than the instantaneous displayed field of view for target detection and initial artillery burst detection and 2) slewing the sensor to position a target or an artillery burst near the center of the field of view prepatory to selecting a narrower field of view. Target and artillery burst designation are performed to obtain target and artillery burst location information and to designate a precision reference point for autotracking. Manual target tracking would be performed during laser designation operations for precision guided munitions. The manual tracking would be an autotracker assist, correcting for autotracker drift and aimpoint shifts.

Coarse Sensor Slewing

Coarse sensor slewing performance has been shown to degrade significantly as frame rate decreases below about 2 frames per second[1]. Sensor control mode appears to have little affect on an operator's ability to perform coarse sensor slewing, regardless of frame rate[1]. Coarse sensor slewing for target and artillery burst detection RPV operations, therefore, should not be performed with frame rates below 2 frames per second. The current RPV system utilizes frame rates as low as 0.12 frame per second in the search mission/mode when target search is performed and 0.94 frame per second in the artillery mission/mode when artillery burst search is performed. If the research data on coarse

sensor slewing and frame rate are correct, the RPV mission payload operator will experience considerable difficulty with the current system design in coarse sensor slewing while searching for targets and artillery bursts under high jamming conditions when low frame rates are employed.

Target and Artillery Burst Designation

The three laboratory studies that investigated sensor slewing for target designation indicate that with a conventional rate control system, frame rates as low as 2 or 4 frames per second will not degrade operator performance[1,2,4]. With frame rates at and below 1 frame per second, the operator's ability to slew the sensor to place a target under a fixed set of crosshairs in the center of the display is degraded — the degradation increasing in an exponential fashion as frame rate decreases. Control aiding techniques, such as image motion compensation and cursor designation previously discussed, however, allow precision designation at frame rates as low as the 0.12 frame per second investigated in the research surveyed[1,4]. Designation of artillery bursts should be equally sensitive to frame rate and sensor control mode as is target designation. Therefore, the design parameter requirements for these two design parameters should apply equally to target and artillery burst designation operations.

The Army RPV system design contains three techniques for target and artillery burst designation: 1) conventional rate control sensor slew using a force actuated joystick control, 2) light pen designation, and 3) offset tracking in which the sensor and a tracking box on the display are slewed via the joystick control. The rate control system and the offset tracking technique will work well with frame rates as low as 2 to 4 frames per second. The light pen designation technique should work well at very low frame rates — it being roughly analogous to the cursor designation technique investigated in the research surveyed. However, it is our understanding that the algorithm for sensor slewing using the light pen designation technique uses a fixed 1800-meter range. As the real range to the object designated departs from the 1800-meter assumed range, sensor slewing is in error. Multiple light pen designations will be required to reduce the error.

The offset tracking mode is intended to be used during autotracking when laser designation for precision guided munitions is required. The technique allows the target aimpoint to be changed without disturbing autotracking. This technique should also work well at frame rates as low as 2 to 4 frames per second. In the track mission/mode where such precision laser designation occurs, the lowest frame rate in the current RPV system design is 3.75 frames per second.

Target Tracking

The available data on manual target tracking with reduced frame rate indicate relatively little degradation in tracking performance between 30-frame per second and 3.75-frame per second frame rates with conventional rate control tracking systems[2,9]. There was no available research which investigated the effects of reduced frame rates with different sensor control modes. In the Army RPV system, manual target tracking (tracking autotracker aimpoint shift and drift) would be accomplished using the rate control system with the joystick control. The lowest RPV system frame rate for operation in a high jamming environment is 3.75 frames per second. It can therefore be concluded that there will be no difficulty in target tracking with any of the seven antijam levels. In fact, lower frame rates could be used with the first six antijam levels that have frame rates greater than 3.75 frames per second. Such lower frame rates provide the option of either further reducing the data rate or decreasing the reduction in resolution and/or video truncation.

Other Parameter Effects

Video truncation should not be used during coarse sensor slewing, because coarse sensor slewing is used in conjunction with target and artillery burst search and detection when a large displayed ground area is desired for efficient search as previously discussed. However once the target or artillery burst has been detected, the sensor slewed to place the target or artillery burst near the center of the field of view, and autotracking is engaged, video truncation is a reasonable means of reducing data rate. The discussion of video truncation and target recognition also applies to designation of a target or artillery burst; the amount of truncation possible depends on the

field of view and the size of the displayed video are necessary to contain the target or artillery burst. As previously stated, with a 2.7-degree sensor field of view the video could be truncated by a factor of 20:1 in both dimensions and still contain a target 7.6 meters in length.

Video truncation is probably best suited for relatively long duration target tracking after the target has been detected and recognized, the target is near the center of the field of view, and the autotracker is engaged. As before, the amount of truncation possible is primarily dependent upon the field of view selected and is only limited by the amount of ground area necessary to contain the target.

Video truncation provided in the current RPV design is independent of sensor field of view. Only with the maximum available 8:1 truncation at the minimum video data rate and with a 1.8-degree field of view would a large target oriented broadside be truncated. Thus the amount of truncation in the RPV is somewhat conservative; considerably greater truncation would be possible at fields of view larger than 1.8 degrees.

Electronic zoom provides increased scale factor of the displayed video, making the displayed size (visual subtense) of the displayed sensor data larger. This increased visual subtense could improve the operator's ability to designate targets, designate artillery bursts and track targets. This was demonstrated in the previously cited research by Fulkerson, Hershberger, and Scanlan[9] in which 2X and 4X electronic zoom improved operator target tracking by 24 and 34 percent, respectively, compared to 1X electronic zoom. Further increases in electronic zoom would presumably further improve manual target tracking up to the point at which the target loses its coherency.

The current Army RPV system design provides operator-selectable electronic zoom when video truncation is used. The amount of electronic zoom, 2X or 4X, is automatically determined, depending on the amount of video truncation. For example, at "Antijam Level 4" there is 4:1 video truncation in the track mission/mode (when the mission calls for precision laser designation for laser guided munitions). In this condition, a 4X electronic zoom would occur if the operator selected electronic zoom. At "Antijam Level None", there is no video truncation, therefore, electronic zoom is unavailable. The result of this design implementation is that the potential benefits of electronic zoom for

improving operator target designation and tracking are coupled to antijam operations rather than the operator's performance requirements. A better design might be to make electronic zoom available any time the operator wishes to use it or to couple it to mission/mode requirements as opposed to video truncation and antijam level.

ARTILLERY BURST SEARCH AND DETECTION

The literature survey did not uncover any research addressing artillery burst search and detection. Image quality parameters are expected to be important but not as critical as they are for target search and detection, because artillery bursts will be relatively large and detection will be improved by movement of the burst. Thus 2-bit per picture element compression should not degrade the operator's ability to detect artillery bursts, and sensor resolution is probably less important than for target detection. Data rate reduction via sensor resolution reduction would seem to be reasonable. How much resolution reduction could be used without degrading performance is difficult to say. The current RPV system provides up to 2:1 resolution reduction in azimuth (240 resolution elements) and 4:1 resolution reduction in elevation (160 resolution elements). Either simulation or flight test will be necessary to determine if the amount of resolution designed into the RPV system is about the right amount, too much, or a greater amount of resolution reduction could be used for the detection of artillery bursts.

A large field of view compatible with the required sensor resolution (TV lines across the burst) should be used to maximize the likelihood of the first artillery burst occurring in the instantaneous displayed field of view. For this reason, video truncation and electronic zoom should not be used for artillery burst search and detection, because the displayed field of view is reduced with video truncation and electronic zoom. The 20-degree diagonal RPV sensor field of view without video truncation and electronic zoom is probably best for initial fire-for-effect artillery burst detection.

The research dealing with video frame rate and target detection performance clearly indicates that target detection performance is unaffected by frame rates as low as 0.12 frame per second[4,6,8]. At first glance, this finding would also seem to apply to artillery burst detection. However, two

additional factors enter into artillery burst detection: 1) the transitory nature of the burst and 2) the dynamics of the burst which should aid in its detection. With very low frame rates, the burst may not be captured on the video frame transmitted, the origin point of the burst may be difficult to determine, and the dynamics (movement) of the burst will not be discernible. Our best estimate of the lowest frame rate that should be used for artillery burst detection is 1 frame per second. The lowest frame rate planned for the Army RPV during the artillery mission/mode is 0.94 frame per second. This frame rate occurs at "Antijam Levels 5 and 6." Higher frame rates are used at the lower antijam operating levels (higher data rates). It, therefore, seems that the lowest frame rate for artillery burst detection is well chosen for high jamming level environments; however, lower frame rates than currently planned for the RPV system could be used during low and medium level jamming environments.

DAMAGE ASSESSMENT

Definitive research an operator assessment of battle damage is either non-existent or its availability is restricted. This writer has never come across any research or simulation on operator assessment of battle damage during the last 10 years of work in target acquisition and related areas. Barring any good direct data on the subject, we hazard the guess that the previously established requirements for target recognition are largely applicable to damage assessment. In other words, maximum sensor resolution and a minimum field of view are the prime parameters to achieve maximum image quality to determine battle damage. A low frame rate and video truncation are practical means to reduce video data rate in jamming environments, and electronic zoom may help in damage assessment by providing a larger displayed image scale factor.

SUMMARY OF BANDWIDTH COMPRESSION/REDUCTION SYSTEM DESIGN RECOMMENDATIONS

The RPV bandwidth compression/reduction parameters recommended for the mission payload operator tasks discussed above are summarized in Table 10. In large part, the recommended parameter values are in agreement with the current Army RPV system design. There are, however, a few deviations and unknowns

TABLE 10. OPERATOR TASKS AND RECOMMENDED RPV SYSTEM DESIGN PARAMETERS

Operator Task	System Design Parameter						
	Bandwidth Compression, Bits/Pixel	Sensor Resolution, TV Lines Across Target Height	Sensor Field Of View, Degrees	Video Truncation	Video Frame Rate, Frames/Second	Sensor Control Mode	Electronic Zoom
Target Search and Detection (Groups of Targets)	2	3	8.4 maximum	None	0.075 minimum	NA	None
Target Recognition	2	8	3.6 maximum	20:1 maximum	Frame update not required after first frame	NA	TBD
Sensor Pointing (Coarse Sensor Slew)	NA	NA	NA	None	2.0 minimum	No effect	None
Target and Artillery Burst Designation	NA	NA	NA	Field of view dependent. Up to 20:1 possible	2.0-4.0 minimum	Rate control	TBD
					0.075 minimum	Aided control	
Target Tracking	NA	NA	NA	Field of view dependent. Up to 20:1 possible	3.75 minimum	Rate control	TBD
Artillery Burst Detection	2	3	20	None	1.0 minimum	NA	None
Damage Assessment	2	8	1.8	8:1 maximum	Frame update not required after first frame	NA	TBD

as follows. Frame rate could be reduced to 0.075 frame per second during target search and detection, compared to the 0.12 frame per second current design value. Coarse sensor slewing frame rate to search for targets outside the displayed sensor field of view should not be less than approximately 2 frames per second. The current system uses a 0.12 frame per second frame rate at the highest antijam level. For target recognition and damage assessment operations, frame update is not required after the first image containing the target at the desired image conditions has been transmitted.

Video truncation could be used during target recognition, target designation, artillery burst designation, target tracking, and damage assessment operations. The current RPV system design utilizes video truncation only during the track mission/mode. Video truncation greater than the current 8:1 maximum is also possible when fields of view greater than 1.8 degrees are used.

The optimum level of electronic zoom needs to be determined. Also electronic zoom may be beneficial to target designation, artillery burst detection, and damage assessment. Since electronic zoom is only available when video truncation is used in the current RPV system, it is unavailable in the search and artillery mission/modes when these operations would occur.

SECTION 5

RESEARCH AND SIMULATION REQUIREMENTS FOR THE ARMY RPV SYSTEM

INTRODUCTION

Considerable parametric research specifically directed at RPV video bandwidth compression/reduction has been conducted during the past 5 years. While this research has supplied needed information to specify RPV system design parameters, it does not cover all the bandwidth compression/reduction design issues. In this writer's judgment, sufficient data exist to specify the level of transform bandwidth compression which should be used, and most of the design issues regarding video frame rate reduction can be resolved from the research that has been conducted. Other RPV design areas, such as resolution reduction for artillery burst detection and the general use of video truncation and electronic zoom, are less well understood. It is also the case that the parametric research conducted has employed past-task simulation in which operator tasks or task elements were investigated in isolation. Thus potential interactions among operator tasks are largely unexplored as are interactions among system parameters, and among system parameters and complete operator task sequences. It would therefore seem that the current Army/Lockheed RPV system development could profit by additional research and simulation that is specifically directed at the Army RPV system.

As a result of the analysis and synthesis of video bandwidth compression/reduction operator performance research data, the description of RPV missions and tasks, and the analysis of RPV operator tasks and bandwidth compression/reduction system design performed during this program, several candidate research and simulation requirements have been identified. In this last section of this report, these research and simulation requirements will be enumerated and a possible implementation of a RPV simulation will be described.

CANDIDATE RESEARCH AND SIMULATION STUDY AREAS

The candidate research and simulation study areas can be grouped into two major categories: 1) RPV system parameter design studies and 2) RPV Mission Payload Operator task sequence simulation and evaluation.

RPV System Parameter Design Studies

Video Frame Rate. Although considerable research has been conducted to determine video frame rate requirements for RPV systems, five candidate study areas have been identified to support Army RPV system development. These candidate study areas are as follows:

1) Investigate the use of a 0.06-frame per second frame rate on RPV operator target search, detection, and recognition performance. The 0.06-frame per second frame rate would provide an additional 2:1 video bandwidth reduction.

2) Investigate the feasibility of interrupting video transmission during target recognition after the narrow field of view video frame containing the target has been transmitted.

3) Verify the degradation of operator coarse sensor slewing performance with frame rates less than 2 frames per second. The current RPV system design utilizes frame rates as low as 0.12 frame per second during target search and detection when coarse sensor slewing would occur. Past research results indicate a major degradation of operator coarse sensor slewing performance with frame rates below 2 frames per second[1]. The research results should be verified in the context of realistic RPV task procedures and system design parameters.

4) Investigate the possibility of using lower frame rates in the track mission/mode under low and intermediate level jamming conditions. The current RPV system uses frame rates of 15 and 7.5 frames per second at the low and intermediate antijam levels. Past research indicates minimum degradation of operator tracking performance at 3.75 frames per second[2,4]. The feasibility of using a 3.75-frame per second frame rate to further reduce the video data rate or in lieu of sensor video truncation to achieve a given video data rate should be explored.

5) Determine the relationship between video frame rate and artillery burst detection performance. The optimum frame rate that does not degrade operator detection of artillery bursts and provides maximum reduction of video data rate is unknown. A research study which determines this relationship is needed.

Sensor Video Resolution. Resolution requirements for detection and recognition of military targets is a well researched area. Research dealing with the effects of resolution on the detection and designation of artillery bursts, however, is lacking. Since the current RPV system design uses resolution reduction to reduce video data rate, the relationship between sensor

resolution and artillery burst detection and between sensor resolution and artillery burst designation should be determined.

Sensor Video Truncation and Electronic Zoom. Video truncation is one of the three methods employed in the RPV to reduce video data rate, and electronic zoom is an available operator-selectable display option when video truncation is used. The effects of both these parameters on operator task performance have not been well researched. Although the analysis of video truncation and electronic zoom levels selected for the RPV appear to be good design choices, they need to be verified. In addition, there are four additional issues for the use of video truncation and electronic zoom that warrant investigation. These four issues are identified below:

1) The use of video truncation during the target recognition process may provide a potential, albeit short duration, means of reducing video data rate.

2) It appears that considerably greater amounts of video truncation than used in the current RPV system are possible when fields of view greater than 1.8 degrees are used. Increased video truncation would allow further reduction in video data rate or less reduction of other video bandwidth parameters.

3) The use of 4X electronic zoom may disrupt the coherency of the displayed video image sufficiently to degrade operator tracking performance. The example of 4X electronic zoom with a 1.8-degree field of view image shown earlier in Figure 37 indicates borderline image quality. This possibility should be investigated.

4) The use of electronic zoom to increase the displayed scale factor of video images may be beneficial to operator task performance other than during the track mission/mode. Electronic zoom (increased scale factor) has been shown to improve operator tracking performance and can improve target aimpoint designation. It may be advantageous to provide this improved performance potential other than during operations when video truncation is used in the track mission/mode and during artillery burst designation.

Interactions Among System Design Parameters. While the past parametric research on RPV video bandwidth compression has investigated selected parameters in combination, one area of potential interaction between RPV system design parameters that has not been evaluated is for video frame rate and video resolution. Since these two parameters are major bandwidth reduction parameters in the Army RPV system, it would be worthwhile to investigate the

the effects of these two parameters in combination for target and artillery burst search, detection, recognition, and designation.

Mission Payload Operator Task Sequence Simulation Study Areas

The Mission Payload Operator's ability to perform task sequences within the operating constraints of the target acquisition/designation and aerial reconnaissance missions is largely unexplored. This is particularly true for operator transitions across tasks and system modes as well as individual tasks largely unique to Army RPV system requirements. Six candidate operator task sequence study areas have been identified and are briefly discussed below.

Multiple Target Designation. RPV missions that support conventional and precision-guided artillery delivery will require operator designation of multiple targets in a sequential fashion. Procedures for selecting individual targets in a complex target array for designation and transitioning among targets need to be developed and evaluated. The Copperhead weapon that is fired in volleys of four weapons at 45-second firing intervals is of particular concern because of the timing restrictions.

Mode Transition Operations. During RPV mission payload operations, the Mission Payload Operator will be required to transition through several modes, performing various tasks in the different modes. Depending on the mission/mode and the jamming environment, the video bandwidth reduction parameters will change. For example, resolution may decrease by a factor of two and frame rate may increase by as much as a factor of 32. The impact, if any, of the changing system parameters across modes on operator performance as well as the changing task demands as the operator progresses from search and detection to target recognition and designation and finally to artillery adjustment or tracking should be investigated.

Light Pen Designation. Very low frame rates may be used during the search mode under severe jamming conditions. The light pen designation technique is intended to be used during such conditions. The operator's performance using the light pen and the impact of the system designation error which can result when the actual range from target departs from the assumed 1800-meter range used in the light pen designation algorithms should be assessed.

Offset Tracking. The offset tracking mode is used to make small refinements in the target aimpoint without going out of autotrack. The scene track, feature track, and offset track modes are used interactively to command offset tracking operation. Procedures for using the offset tracking capability should be evaluated during artillery and track mission/mode operations.

Artillery Adjustment Operations. All of the existing behavioral research data in support of RPV system design and operator performance has addressed target-centered tasks and design issues. The use of RPVs for artillery adjustment is a barren area with regard to operator task performance.

Since artillery adjustment is a major Army RPV mission/mode, the operator's ability to perform artillery adjustment tasks and the impact of video bandwidth compression/reduction in a jamming environment should be evaluated.

Antijam Mode Operation. Protection of the RPV video data link under jamming conditions is achieved by reducing the bandwidth (data rate) of the video downlink. This protection is under the control of the Mission Payload Operator. Jamming is detected by the operator by observation of the sensor video which is degraded in quality. The operator then selects one of six available antijam levels on a rotary control switch which causes a reduction of the video data rate which then results in a reduction of the bit error rate jamming and an improvement of the video image quality.

How the operator will use the antijam control during jamming conditions is unexplored. For example, at Antijam Levels 5 and 6, it can take 4.3 and 8.6 seconds, respectively, before the operator sees the results of selecting the antijam level in the search mode. How easy it will be for an operator to select the appropriate level of antijam based on the jammed video image quality is also unknown. Similarly, the operator's ability to operate at the various combinations of data rate reduction parameters and RPV mission modes needs to be assessed.

AN APPROACH FOR A RPV SIMULATION IMPLEMENTATION

In the preceding identification of candidate RPV research and simulation study areas, 17 such study areas were briefly outlined. It would therefore

seem that there is ample need for continued research and simulation of mission payload operations to support the development of the Army/Lockheed RPV system. The most urgent area of simulation needed is Mission Payload Operator procedures which at this time are largely unexplored. The two major requirements for such a simulation are timeliness and full mission/task closed-loop capability.

There are many possible implementations of such a simulation effort. One possible approach, which is based on current hardware and computing equipment residing at Hughes Aircraft Company, is briefly described here.

Evaluation of RPV mission procedural algorithms for use under normal and jamming conditions requires a simulation of the major tasks and mission environment of the Mission Payload Operator. The major tasks of the MPO include target search, detection, recognition, acquisition, and track; laser designation; and artillery adjustment. These mission activities and their associated subtasks may be simulated using computers and equipment as shown in Figure 46.

The block diagram of Figure 46 shows sources of sensor video to accommodate fields of view from 20 to 1.8 degrees diagonal while maintaining at least 525-line TV resolution and necessary scene dynamics. These video sources are identified as search, recognition, and track/artillery adjustment to identify their use during a simulated mission. The search video source uses a 35-mm motion picture film projector to provide dynamic images of the terrain as it would appear to the on-board sensor. The second video source uses a random access 35-mm still projector to provide detailed terrain images for target recognition, artillery adjustment, and laser designation, using wide and narrow fields of view.

Each of the film projectors is coupled to a television camera which converts the optical image to standard RS-170 video. The cameras are driven by a sweep generator which provides horizontal and vertical deflection to the vidicon raster as well as horizontal and vertical synchronization pulses.

The sweep generator allows the size of the vidicon raster in the camera to be continuously varied from full-size to one-half-size providing a 2:1 zoom capability for field of view change. Although it is possible to vidicon raster zoom by factors greater than two, the granularity of the vidicon and the size

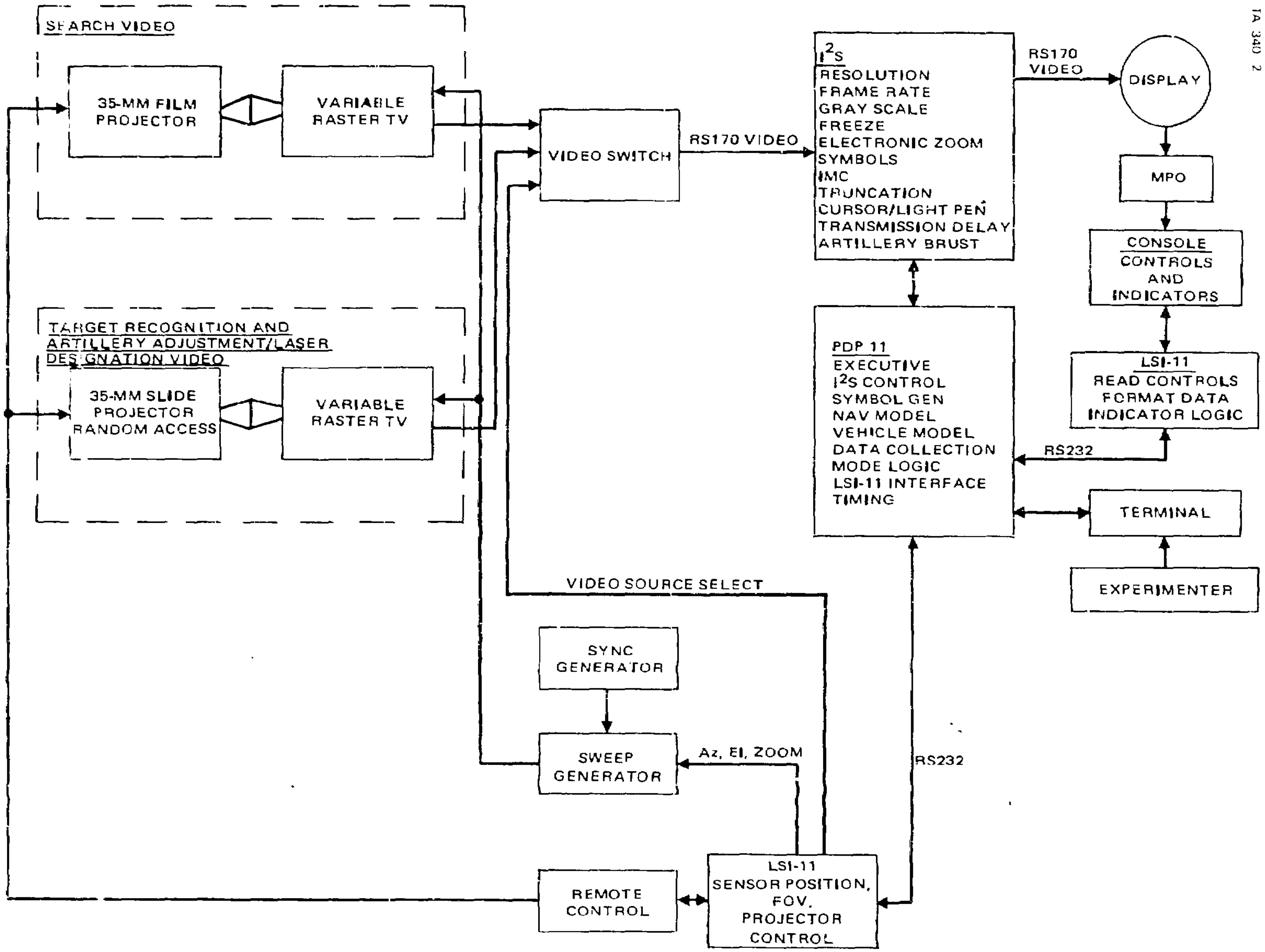

Figure 46. Simulation functional block diagram.

of the raster electron beam cause a loss of resolution. Because loss of resolution would confound the results of the simulation evaluations, raster zoom is limited to two-to-one.

The sweep generator also allows the position of the raster to be externally controlled, simulating sensor slew. The extent to which the raster may be moved depends upon the amount of zoom selected. When zoomed two-to-one a total of four instantaneous fields of view form the total field of view on the film and considerable slew is possible. The combination of film projectors and raster subscanning provides the needed fields of view and sensor slew capability.

The position inputs for the sweep generator are provided by an LSI-11 microcomputer tied to a real-time PDP-11/34 computer which controls the overall simulation. The LSI-11/PDP-11 interface is an RS-232, 9600 baud, serial link which is easy to implement and adequate for the data rates involved.

The LSI-11 which controls the sweep generator also provides projector remote control, slide selection, and video source selection. This LSI-11 and the other LSI-11s in the simulation would be equipped with the necessary conversion hardware to provide both analog and digital input and output. The LSI-11s should be located near the equipment they control to minimize the length of the cables between the equipment and the processor. A single line connects the peripheral LSI-11 to the central PDP-11. By distributing the processing, the data rate to the PDP-11 may be significantly reduced and the length of noise-susceptible analog signal cables is minimized.

A I^2S Stanford Technology Corporation image computer would perform virtually all of the bandwidth reduction/compression simulation functions under control of an embedded LSI-11 microcomputer and the PDP-11 computer. Resolution, frame rate, image truncation, electronic zoom, image freeze, gray scale manipulation, jamming, and image motion compensation are among the functions which the I^2S would perform in the simulation. The particular combinations and levels of each of these functions can be dynamically altered in real-time by the controlling computers. The I^2S also has graphic overlay capability and a built-in vector generator which allows dynamic symbology to be superimposed over the sensor video.

The video output of the I^2S would be displayed on a high quality TV monitor for viewing by the MPO in the simulation. The display would be physically located in a console with all of the controls, indicators and switches to be found in the actual RPV system. The layout of the panel and the complement of controls includes a hand control, light pen, field of view select switches, autotracker controls, laser controls, sensor package controls, and various indicators. The controls would be read and the indicators driven by a LSI-11 interfaced to the PDP-11 computer. Again the link between the processors would be RS-232.

Control of the simulation would be accomplished by the experimenter via a CRT terminal into the PDP-11. All variables and initial conditions would be set from this terminal either manually or by reference to a disc file which contains previously selected combinations and levels of variables. This terminal may be located next to the MPO in the simulation, in another room, or any other desired location.

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